JOURNAL of the AMERICAN SOCIETY *of* *NAVAL ENGINEERS* Inc.

November, 1960

Volume 72 Number 4

Presidents of the

AMERICAN SOCIETY OF NAVAL ENGINEERS, INC.

REAR ADMIRAL ROBERT E. CRONIN, U. S. NAVY

Past Presidents

1889-90	*Chief Engineer Nathan P. Towne, U. S. Navy*
1891	*Past Assistant Engineer G. W. Baird, U. S. Navy*
1892	*Chief Engineer David Smith, U. S. Navy*
1893-94	*Chief Engineer H. Webster, U. S. Navy*
1895	*Chief Engineer James H. Perry, U. S. Navy*
1896	*Chief Engineer E. D. Robie, U. S. Navy*
1897	*Chief Engineer David Smith, U. S. Navy*
1898-99	*Chief Engineer H. Webster, U. S. Navy*
1900	*Commander H. Webster, U. S. Navy*
1901-02	*Commander C. W. Rae, U. S. Navy*
1903	*Lieutenant Commander W. M. Parks, U. S. Navy*
1904	*Rear Admiral John D. Ford, U. S. Navy*
1905	*Commander A. F. Dixon, U. S. Navy*
1906	*Commander A. B. Canaga, U. S. Navy*
1907	*Commander B. C. Bryan, U. S. Navy*
1908	*Commander R. S. Griffin, U. S. Navy*
1909	*Rear Admiral John K. Barton, U. S. Navy*
1910-11	*Engineer-in-Chief H. I. Cone, U. S. Navy*
1912-13	*Captain R. S. Griffin, U. S. Navy*
1914	*Rear Admiral J. R. Edwards, U. S. Navy*
1915	*Captain S. S. Robison, U. S. Navy*
1916	*Captain C. W. Dyson, U. S. Navy*
1917-18	*Captain H. P. Norton, U. S. Navy*
1919	*Rear Admiral H. P. Norton, U. S. Navy*
1920	*Rear Admiral C. W. Dyson, U. S. Navy*
1921	**Captain A. J. Hepburn, U. S. Navy**
1922	*Rear Admiral C. W. Dyson, U. S. Navy*
1923-24	*Captain J. T. Tompkins, U. S. Navy*
1925	*Rear Admiral C. F. Hughes, U. S. Navy*
1926	*Rear Admiral M. M. Taylor, U. S. Navy*
1927	*Rear Admiral John Halligan, U. S. Navy*
1928	*Captain E. L. Bennett, U. S. Navy*
1929-30	*Rear Admiral H. E. Yarnell, U. S. Navy*
1931	**Rear Admiral S. M. Robinson, U. S. Navy**
1932	*Rear Admiral F. B. Upham, U. S. Navy*
1933	*Rear Admiral William A. Moffett, U. S. Navy*
1933	*Rear Admiral E. J. King, U. S. Navy*
1934-36	**Rear Admiral William H. Standley, U. S. Navy**
1937	**Rear Admiral Alfred W. Johnson, U. S. Navy**
1938	**Rear Admiral Harold G. Bowen, U. S. Navy**
1939	**Rear Admiral S. M. Robinson, U. S. Navy**
1940	**Rear Admiral Henry Williams, U. S. Navy**
1941	*Captain Claud A. Jones, U. S. Navy*
1942	**Rear Admiral Herbert S. Howard, U. S. Navy**
1943	*Rear Admiral J. J. Broshek, U. S. Navy*
1944	*Rear Admiral C. L. Brand, U. S. Navy*
1945	**Rear Admiral E. W. Mills, U. S. Navy**
1946	*Rear Admiral Harvey F. Johnson, U.S.C.G.*
1947	**Rear Admiral C. W. Styer, U. S. Navy**
1948	**Rear Admiral Roger W. Paine, U. S. Navy**
1948	*Rear Admiral Harvey F. Johnson, U.S.C.G., Ret.*
1949	**Rear Admiral T. A. Solberg, U. S. Navy**
1950	**Rear Admiral F. E. Haeberle, U. S. Navy**
1951	**Rear Admiral David H. Clark, U. S. Navy**
1951	**Rear Admiral Louis Dreller, U. S. Navy, Ret.**
1952	**Rear Admiral T. C. Lonnquest, U. S. Navy**
1953	**Rear Admiral Homer N. Wallin, U. S. Navy**
1954	*Rear Admiral Evander W. Sylvester, U. S. Navy*
1955	**Rear Admiral W. D. Leggett, Jr., U. S. Navy**
1955	**Rear Admiral F. R. Furth, U. S. Navy**
1956	**Rear Admiral Kenneth K. Cowart, U.S.C.G.**
1957	**Rear Admiral Albert G. Mumma, U. S. Navy**
1958	**Rear Admiral Leroy V. Honsinger, U. S. Navy**
1959	**Rear Admiral William A. Dolan, U. S. Navy**

*Names in italics deceased

JOURNAL

of

The American Society of Naval Engineers, Inc.

PUBLISHED QUARTERLY

UNDER THE SUPERVISION OF THE COUNCIL

Rear Admiral Robert E. Cronin, USN, President

Commander R. S. Burpo, Jr., USNR

Commander John A. Coil, USN

Mr. Gilbert S. Frankel

Mr. Harold H. Hill

Captain Frank C. Jones, USN

Rear Admiral M. J. Lawrence, USN

Commander Ralph S. Lorimer, USNR

Captain Thomas W. Rogers, USN

Rear Admiral E. H. Thiele, USCG

Captain J. E. Hamilton, USN (Ret.), Secretary-Treasurer

SEVENTY-SECOND YEAR

VOLUME 72 NOVEMBER, 1960 NUMBER 4

Published Quarterly at Washington, D.C., by The American Society of Naval Engineers, Inc.

Entered as Second Class Matter at the Post Office at Washington, D.C., and at Nashville, Tenn. Acceptance for mailing at special rate of postage provided for in Section 1103, Act of October 3, 1917, authorized on July 3, 1918.

Subscription Rates for Non-Members

The subscription price of the JOURNAL, postpaid to points in the United States and possessions is $12.00. Single copies, $3.00. To other countries, $20.00. Single copies, $5.00. All subscriptions payable in advance.

Make checks, drafts and postal money orders payable to THE AMERICAN SOCIETY OF NAVAL ENGINEERS, INC.

Advertising rates will be furnished on application.

Addresses will be changed at any time, but only upon notification. Immediate notice should be given of any delay in the receipt of the JOURNAL.

Address all communications for the Society to

THE AMERICAN SOCIETY OF NAVAL ENGINEERS, INC.

Suite 403, Continental Building
1012 14th Street, N.W.
Washington 5, D.C.

The American Society of Naval Engineers, Inc., has no official connection with the Navy Department.

TABLE of CONTENTS

PAGE

Secretary's Notes 601

Marine Applications of Plastics
by CAPTAIN T. B. OWEN, USN and MR. J. B. ALFERS 609

Early French Contributions to the Theory of Specific Heats
by DEAN J. H. POTTER 623

Magnetohydrodynamic Generators
The *Westinghouse Engineer*, July 1960 629

Machinery Proposals for a Mammoth Liner
The *Marine Engineer and Naval Architect*, April 1960 633

Nuclear Power for Ship Propulsion
Journal of the Institute of Fuel, June 1960 643

Graphical Checking of Test Data
by ASSOCIATE PROFESSOR HILBERT SCHENCK, JR. 653

Can Design Eliminate Forebody Damage
Marine Engineering/Log, May 1960 659

Gas Turbine Propulsion for Hydrofoil Boats
Mechanical Engineering, June 1960 667

Modern Models and Model Making
by DONALD L. HERR 673

Marine Engineering Notes from the Soviet Press
by COMMANDER B. M. KASSELL, USN (Ret) 675

Basic Control Concepts for Pressurized Water Reactors
by LIEUTENANT A. G. STIRLING, USCG 693

Recent Developments in Pump Auxiliaries for Ships
Transactions of the Institute of Marine Engineers, June 1960 699

Studies of a Plasma Pinch Space Engine
by Irving Granet, Dr. Wm. Guman and Dr. Wm. McIlroy 715

An Advanced Concept for Commercially Profitable Land and Marine Nuclear Power: The High Temperature Gas Cooled Pebble Bed Reactor
by Lieutenant Robert J. Bosnak, USCG 727

The Use of Work Measurement and Work Standards for Control of Productive Work in Shipyards
by Commander R. F. Desel, USN and Mr. L. E. Carlow 737

Extreme-Pressure Lubricants for Marine Gears
The Shipbuilder and Marine Engine-Builder, April 1960 749

A New Concept for a Nuclear Marine Propulsion Plant
by Paul N. Garay 755

Report on 9000 Hour Operation of Marine Propulsion Gas Turbine in the *John Sergeant*
American Society of Mechanical Engineers paper GTP-5 761

Information for Directing Space and Missile Programs
E. B. Hincks and R. W. Bragg 773

Liquid Metal Heat Exchangers
Lieutenant K. B. Schumacher, USCG 779

The Problem of two Different Systems of Measure
by Nebojsa Gasparovic with comment *by* Arnold Buchsbaum 783

DEPARTMENTS

Book Review and Notices 785

Obituary: Captain Henry C. Dinger, USN (Ret) 788

Changes in Membership 791

Association Notes 793

Index to Advertisers 797

THE 1961 ANNUAL BANQUET

of

The American Society Of

Naval Engineers

will be held at

HOTEL STATLER-HILTON

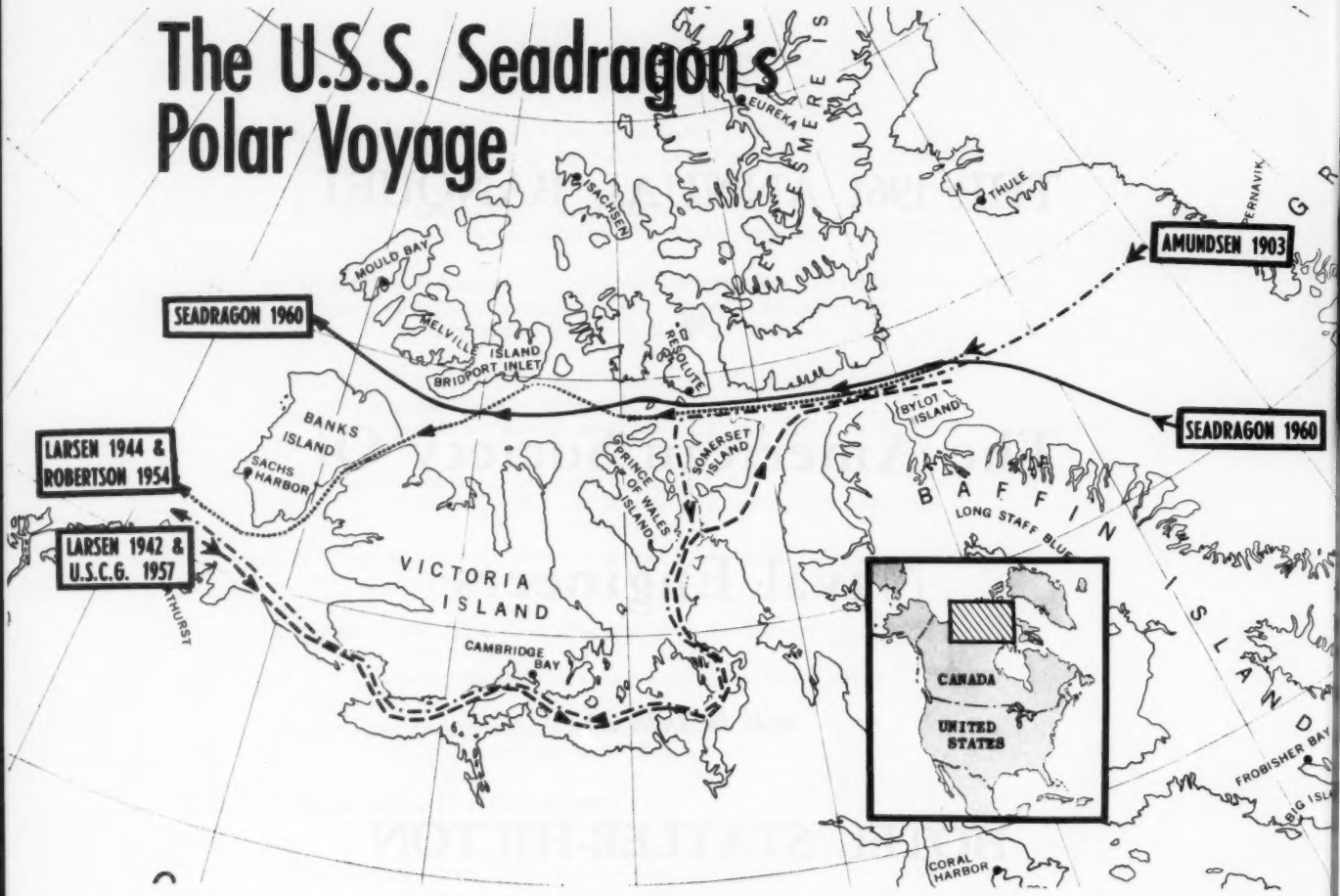
WASHINGTON, D. C.

on

Friday, 28 April 1961

Notices with application forms will be mailed to all members in February 1960.

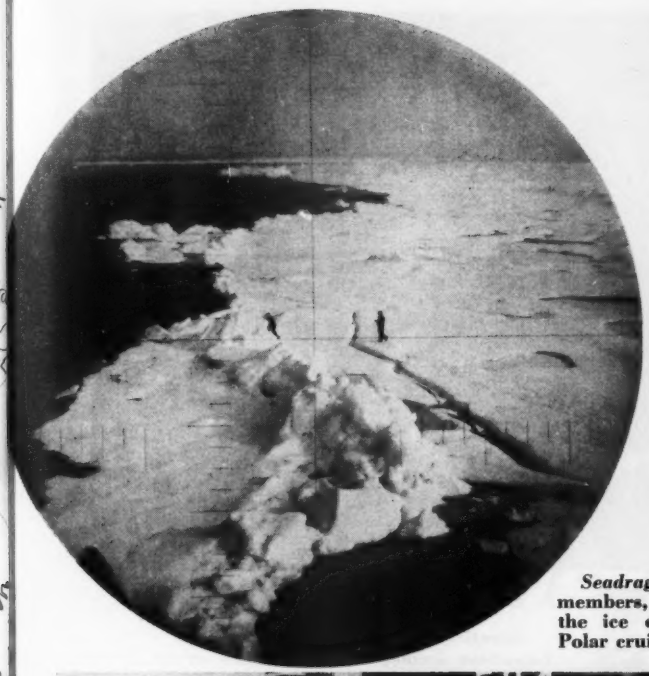
The U.S.S. Seadragon's Polar Voyage



This chart shows routes taken by the six expeditions which successfully completed passage through the Canadian Archipelago. Marked in solid line is the USS *Seadragon's* successful northern route announced by the Navy. First to complete a passage was the Northern explorer Ronald Amundsen, (dot-dash track), whose 47 ton herring boat completed the east-west route south of Victoria Island in 1903-1906. Thirty-five years later, Sergeant R. A. Larsen, made the west-east trip in a Royal Canadian mounted police vessel also south of Victoria Island, in 1940-42 (dash track). In 1944, Larsen made the passage in the *St. Roch* in the opposite direction, (dotted track) along the route that Commodore O. C. S. Robertson, RCN, followed ten years later. Finally, three U.S. Coast Guard ships, the *Storis*, *Spar*, and *Bramble*, followed the Larsen 1940-42, (dash track) west-east route through the Archipelago.

Seadragon **crew members dot the Arctic ice as they collect information during the Polar cruise.**

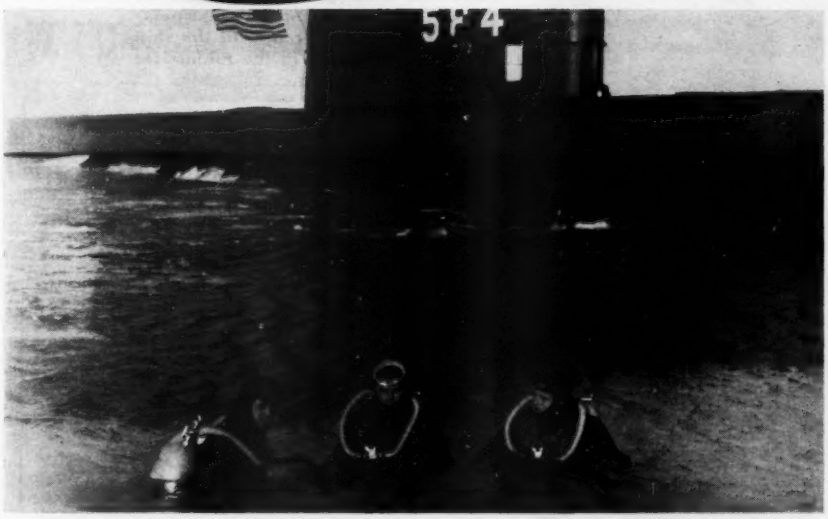
Official U. S. Navy Photograph



Seadragon crew members, explore the ice during the Polar cruise.

Official U. S. Navy Photograph

Seadragon Frogman Earl J. Crowley, TM1 (SS), USN, a member of the underwater photography team, swimming under the Arctic ice in the first series ever made of the underside of the North Pole.



Official U. S. Navy Photograph

Smiling-moustached facile profile on the cliff of this iceberg looks down at the nuclear submarine USS *Seadragon*, on her polar voyage. This iceberg was the largest encountered by the *Seadragon* during her negotiation of the Canadian Archipelago. In diving under the berg, the *Seadragon* found her to be more than 300 feet deep.

Seadragon divers prepare to explore under the North Pole taking the first photographs ever made of the underside of the Arctic ice. Lt. G. M. Brewer, USN (left), E. F. Crowley, TH1 (SS), USN, (Center) and E. P. Quick, EN2(SS), USN, (Right) found the 28.5° water comfortable.

Official U. S. Navy Photograph

Official U. S. Navy Photograph

These icy formations were photographed during one of the first pictorial explorations of the underside of the arctic ice. This photograph was taken by Lt. G. M. Brewer, USN, head of the Underwater Photography team from the U. S. Naval Photographic Center, Washington, D.C. The water temperature was 28.5° Fahrenheit.

Official U. S. Navy Photograph

Scientist Walter I. Whitman, ice forecaster accompanying the crew of the USS *Seadragon* on its trans-polar voyage, stands on the bow of the ship taking weather data in the middle ice pack of Davis Straits.

Official U. S. Navy Photograph

With cold calulation, Richard W. Caron, YNC(SS), USN, unwinds the first toss in the historic premiere North Pole Ball Game. The umpire with the frozen stare and cold heart is A. V. Jarvis, HM1 (SS), USN.

Official U. S. Navy Photograph

Batter up! Thomas J. Miletich, TM2 (SS), USN, is all set for the first ball pitched in the first game to be played at the North Pole. Ready to stop anything that gets by Miletich is opposing catcher, Lt. (jg) Vincent Leahy, USN.

Copyright 1960, by the American Society of Naval Engineers, Inc.

Journal of the AMERICAN SOCIETY of NAVAL ENGINEERS, Inc.

VOLUME 72 NOVEMBER, 1960 NUMBER 4

Statements contained in articles herein are the private opinions and assertions of the writers and should therefore not be construed as reflecting the views of the AMERICAN SOCIETY OF NAVAL ENGINEERS, INC., nor of any other organization with which such writers are affiliated. The Society as a body is not responsible for statements made by individual members.

COUNCIL OF THE SOCIETY

(Under whose supervision this number is published

Rear Admiral ROBERT E. CRONIN, USN, President

Commander R. S. BURPO, JR., USNR
Commander JOHN A. COIL, USN
Mr. GILBERT S. FRANKEL
Mr. HAROLD H. HILL
Captain FRANK C. JONES, USN
Rear Admiral M. J. LAWRENCE, USN
Commander RALPH S. LORIMER, USNR
Captain THOMAS W. ROGERS, USN
Rear Admiral E. H. THIELE, USCG

Captain J. E. HAMILTON, USN (Ret.), Secretary-Treasurer

NAVAL ENGINEERING

Definition: NAVAL ENGINEERING is the art and science applied in the design, construction, operation and maintenance of naval ships and their installed equipment.

SECRETARY'S NOTES

THE ASNE GOLD MEDAL AWARD—1960

Members of the Society are aware of the fact that an annual award is available each year to that citizen of the United States who made the greatest contribution to the advancement of NAVAL ENGINEERING during the year.

The awardee is selected by a board consisting of three past-Presidents of the So-

ciety (assuming that we can assemble this many) from their own knowledge (secondary) and primarily from the citations which are received.

Initially to establish a firm criterion, an official definition of Naval Engineering was adopted. This definition has appeared under the masthead in each issue of the Journal since its adoption.

This is a recently established award and has been made only twice to date. For 1958 the award was made to Mr. Valor C. Smith of the Naval Electronics Laboratory for his contribution in connection with radio antenna design. The 1959 award was received by Dr. Waldo K. Lyon, also of the Naval Electronics Laboratory for his contribution in connection with the development of electronics equipment particularly applicable to submarine operations in Arctic waters.

The Society wants this, its major award, to gain recognition as one of the most important awards in the world for technical achievement. It is intended to be just this. This fact makes it very difficult for executives to recommend their own people for the award for several reasons, including:

Many accomplishments are the result of joint effort and it is difficult to single out an individual for specific credit;

Where, in the opinion of the executive, several things of note have been accomplished, he hesitates to select one as the most important because of fear of an adverse morale effect;

He makes a prejudgment that someone will be cited by someone else whose feat will be considered more outstanding than the best that he has to offer

The outstanding accomplishments of which he is aware probably are not (in his opinion) within the field of Naval Engineering and

Security reasons.

We have tried by display presentations in the Journal and by personal letters to selected Naval Commanders to encourage the submission of citations for this award. To date the response has been very light. The awards committee is convinced that many more things, worthy of consideration are done each year than are placed before them for selection. To what extent this may have colored decisions during the last two years is indeterminate. The committee has no way of evaluating an accomplishment of which it is ignorant.

What has been accomplished during 1960? We can cite continued submarine operations in the Arctic, successful test firing of the POLARIS missile from ***George Washington*** and ***Patrick Henry***, and launching the world's largest ship, the nuclear powered aircraft carrier ***Enterprise.*** These are a few of the end products of Naval Engineering during 1960. They are outstanding because of singular contributions to the field of Naval Engineering in 1959, 1958, 1957 etc. What has been done during 1960 which will make it possible for the realization of outstanding results in 1961, 1962, 1963 etc.? These are the things that we are looking for as well as the 1960 accomplishments which had a final payoff within the same year. This is the sort of judgement which is within the capacity of Naval Engineering executives to make.

Please Note:

Anyone can submit a citation
Any American Citizen may be cited
Naval Engineering is a very broad field
There need be no administrative relationship between the citer and the citee

1960 will end in about a month after you receive this Journal. Has anything been accomplished since 31 December 1959? Has it been outstanding, in your opinion? Do you know who did it? Do you see any connection whatever between this thing and Naval Engineering? Can you describe the accomplishment and the relationship of the man to the deed?

If each reader who sees this can answer all questions affirmatively he owes us a citation for a proposed recipient of the 1960 ASNE Gold Medal Award. Please send it to—

ASNE Award Committee
American Society of Naval Engineers
Suite 403
1012 14th Street, N.W.
Washington 5, D. C.

Typewriting is preferred but legible handwriting is fully acceptable.

JASNE Advertisers

In this issue of the Journal, readers will note a deviation from a policy which has existed for 72 years. On a trial basis, the advertisements are not segregated in one section of the magazine. They are dispersed between the articles.

The ostensible reason for this change is to make advertising in the Journal more attractive to advertisers. By bringing what they have to say into positions in which it is more apt to be seen and read, we are offering them something more for their money than we have in the past. Since they contribute about 20 percent of the income of the Society and thus help appreciably to support a better Journal, we feel that they are entitled to the fullest consideration.

However, there is much more to it than that. These concerns which advertise in the Journal, by that mere fact, display their participation, as organizations, in the profession of Naval Engineering. As organizations they are not eligible to Society membership which is limited to individuals but they want it to be known that they do engage in your profession. They want you to know what they have done; what they are capable of doing. They want you to recognize their connection with you as Naval Engineers.

Considering all of its ramifications, there is no more progressive nor challenging nor rewarding functional engineering field than the one which this Journal, and it alone, among all technical journals, represents. This is a field of ideas, of design, of specification, of production whose end product is the hardware which is the United States Fleets. Of the tens of thousands of engineers who in their specialties, occasionally or continually contribute to the advancement of Naval Engineering, possibly less than one percent are members of the Society. A large majority of these individuals, both members and non-members, are employees in the industrial complex which produces the ships of the Navy and all of the things contained in them. This complex is made up of thousands of concerns which contribute to the complete naval ship ready for its intended use. Of these thousands only a handful, our advertisers, recognize and want the world to recognize, that they are operators in the field of Naval Engineering.

We are proud to publicize this recognition by giving their displays a more prominent position in the Journal. If this should influence other firms to request advertising space so that they too can be known as concerned with Naval Engineering, we can accommodate a few additional. We have no intention of increasing the space devoted to advertising at the expense of the articles which are published. These will be continued on no lesser a scope than has been the recent practice.

There is but one catch. If readers object to this change on the ground that it reduces the dignity of the Journal or that our advertisers do not warrant such special treatment, we will revert to the previous practice. The Council has authorized this for two issues on a trial basis subject to acceptance by the members.

1961 Banquet

The Council has decided that there will be an American Society of Naval Engineers Banquet in 1961. Because of the great success of past banquets it is probable that this action was inevitable. Detailed plans for this affair will be arranged by a committee which has been formed and has started its actions under the chairmanship of the Secretary-Treasurer. The Council has stipulated the following features, which, to the extent of their applicability limit the freedom of the committee:

The 1961 banquet shall be arranged, in general, after the pattern of the one in 1960.

It shall be held on:

Friday, 28 April 1960

at

The Statler Hilton Hotel, Washington, D. C.

For parties of two or four one member may have one non-member guest. For larger parties only one non-member guest to each two members will be permitted. The price, to be set by the committee, shall be the same for non-members as for members.

There will be a favor.

As is the usual practice notices and applications for the banquet will be mailed to all members during late February 1961.

1961-1962 Elections

The Council and the Annual Meeting accepted the report of the nominating committee and approved the recommended slate without change. The names which appear on the ballot which should already have reached voting members are:

For President in 1961 vice Rear Admiral R. E. Cronin, USN; whose term expires on 31 December 1960:

Rear Admiral E. H. Thiele, USCG, Engineer-in-Chief, U. S. Coast Guard

For two naval memberships on the Council to serve during 1961 and 1962 vice Commander John M. Coil, USN and Captain T. W. Rogers, USN (Ret) whose terms will expire on 31 December 1960:

Captain Edward J. Fahy, USN, Assistant Chief Bureau of Ships for Research and Development

Captain Jack A. Obermeyer, USN, Commanding Officer and Director David Taylor Model Basin

Rear Admiral Floyd B. Shultz, USN, Assistant Chief Bureau of Ships for Technical Logistics.

Commander Joe W. Thornbury, USN, Head, Electrical Branch, Bureau of Ships

For one Coast Guard membership on the Council to serve during 1961 and 1962 vice Rear Admiral E. H. Thiele, USCG, nominated for President in 1961:

Captain Gilbert F. Schumacher, USCG, Chief Naval Engineering Division, U. S. Coast Guard Headquarters

Lieutenant Commander John B. Crowley, USCG, Secretary, Ships Structure Committee, U. S. Coast Guard Headquarters.

For one Naval Reserve membership in the Council to serve during 1961 and 1962 vice Commander R. S. Burpo, USNR whose term will expire on 31 December 1960:

Lieutenant Commander C. P. Roane, USNR (Ret), Supervisory Naval Architect, Bureau of Ships

Commander C. M. Featherstone, Jr., USNR, Washington Representative, Northrop Corporation.

For one Civilian membership on the Council to serve during 1961 and 1962 vice Mr. Gilbert S. Frankel whose term will expire on 31 December 1960:

Mr. C. Swan Weber, Vice President, Westinghouse Electric Corporation

Mr. H. C. McCord, District Sales Manager, Aluminum Corporation of America.

Meetings

The Council of the Society held meetings on 31 August and 10 October 1960. The latter meeting is required by the By-Laws as a prelude to the Annual Meeting.

The Annual Meeting was held on 10 October 1960. This was in accordance with the By-Laws which require it to be held and during the first half of October each year. Although only 37 members attended this meeting this was an increase of 20 per cent over the 1959 attendance. This year's meeting was originally scheduled to be held in a room which was completely burned out just 9 days before the meeting. The President commended Commander Thornbury for his expedition in making arrangements for another meeting place and Miss Leonard for having notices of the new location in the hands of members four days after the fire and in plenty of time for the meeting.

The business which was conducted at these various meetings is discussed in other places in these notes.

Change in By-Laws

The following proposed changes in the By-Laws of the Society also appears on the ballot for decision by the membership:

"This is Amendment No. 3 to the November 1957 edition of the By-Laws of ASNE: Delete Article 18 in its entirety and substitute therefore:

The Council shall prepare such regulations as it deems appropriate, consistent with the provisions of this Article, including specific criteria and annual dues, to provide for Student and Junior Memberships.

a. The Council may establish Student Memberships, for which any undergraduate at a school accredited by the Council may be eligible until the end of the calendar year in which he graduates or is separated from the school.

b. The Council may establish Junior Memberships, for which any person is eligible who

a. is eligible for Naval Membership and is less than 30 years of age, or

b. is eligible for Civil Membership except for the experience requirement and is less than 30 years of age.

c. Student and Junior Members shall receive the JOURNAL and shall have all the privileges of regular membership except voting and standing for office.

Articles 14 and 19 are hereby amended to conform to this change to Article 18."

This matter has been discussed in these notes in previous issues of the JOURNAL. If the change is adopted, it is expected that the Council will have promulgated rules and regulations for Student and Junior members in time to reach 1961 graduates while they are still eligible for Student membership.

Form of Ballot and Dues Notice

Members will have noted that the new ballot is in the modern dress which facilitates action. Members have only to mark the ballot and insert it in the fold provided in the return portion. No postage need be added. A similar form will be used when the statement of 1961 dues is mailed. In this latter case the member need only prepare and insert a check.

It is hoped that this simplification will be reflected in a more complete and earlier return.

A Technical Society and Technical Meetings

Occasionally we have heard informal discussions as to whether the Society should modify its activities to more nearly parallel those of other technical societies. This matter is now on the calendar of unfinished business of the Council for consideration of a statement made at the 1960 Annual Meeting by a member, Mr. Uriah L. Allen, Jr. of Baltimore, Maryland. Mr. Allen, who is senior engineer in the

Air Arm Division of Westinghouse Electric Corp., made the point that we were the only technical society which held no technical meetings; that the only ASNE meetings were the annual business meeting and the annual banquet which is social. This is, of course a correct statement. Mr. Allen urged that strong consideration be given to holding at least one technical meeting each year.

In advance of any Council meeting at which this subject was discussed it is impossible to indicate how the discussion will run or what pros and cons will be brought up. The Council will not be able to begin a study until next year. In the meantime it would be a lot of help if interested members would jot down their views with reasons and send them to the Secretary-Treasurer to assemble for the Council.

The following points appear to be pertinent.

Several years ago, on the strong urging of a group of members, the By-Laws were amended to permit forming local chapters of the Society. The purpose as set forth at the time was to set up small organizations which could read and discuss technical papers which would become a source of articles for the JOURNAL. It was also expected that these groups would draw new members into the Society. Up to this time, although there have been a number of inquiries, in no locality has the necessary twelve members banded together to form a local chapter. This may be due to a lack of interest in another technical meeting or it may merely mean that necessary leadership to form a chapter has been missing.

The arrangements for the Annual Banquet are handled by the regular Society staff with a very small temporary addition of clerical help. Only the extra help is charged to banquet expense. Over the years the banquet balance has been both red and black and it is estimated that the net of this in 41 years has been about one-third of what would be charged if the Society's general expense was prorated and charged to the banquet account. Just what the effect on the Society's treasury would be if technical meetings were added to our present program is indeterminate.

If technical meetings are held they could, of course, be added to the program of the Annual Banquet or they could be scheduled for another time of year or at another location. The banquet has gained some reputation for what it has been and there are very strong arguments for retaining its traditional nature. This nature has two important features. For the local people the evening comes at the end of the working week which is not interfered with and it gives them an opportunity to renew many acquaintances, possibly to discuss business or technical matters but probably more usually to escape from these. For the out of towners, it need not be much different in this jet age but many of them do arrive a day or a few hours early so that they can take advantage of a visit to Washington to take care of some kind of business with the government. Both of these features would seem to point to the desirability of complete separation in time between any technical meetings and the annual banquet. It is quite possible, anyway, that many of the individuals who now attend the banquet would not attend technical meetings but would continue to operate just as they do now. It is equally possible that many members do not come to the banquet but would be keenly interested in attending technical meetings whether or not interlarded with social affairs.

For members who do not attend the banquet, and this is about two-thirds of the ASNE membership, the Society furnishes the quarterly JOURNAL which carries about eighty articles, allied in some fashion to Naval Engineering, each year. Occasionally these articles elicit discussions which are also published in the JOURNAL. This same sort of thing is handled in various ways by other technical societies. A general picture is that papers are presented, some only in abstract, and discussed at technical meetings, copies of individual papers with discussion are available to members and some of the papers are published in society or associated periodicals. As a matter of interest, our JOURNAL quite often carries reprints of papers which have been presented at technical meetings of other societies.

There will be problems to consider in deciding whether or not to hold technical meetings. A small number of these are indicated above. It is hoped that every member who has ideas on the subject will send them in for the benefit of the Council.

It should be noted that the Council has authority to set up technical meetings if it should decide to do so. In the past, even when it could act, the Council has usually submitted important matters, and this is believed to be an important matters to the full membership as a change in the By-Laws. It is hard to predict what may happen in this case. No prediction will be made now. Please let us hear from you.

SUMMARY OF SUBMARINE EXPLORATIONS IN THE ARCTIC

The earliest recorded thoughts that a "submarine ark" should be used for "Submarine Navigations" was advanced by Bishop John Williams in 1648 in his book "Mathematical Magick." Subsequently, Dr. Vilhjulmar Stefansson, Sir Hubert Wilkins, and others have advanced ideas concerning using a submarine for arctic exploration. Stefansson relates that his idea germinated by observing whales surfacing in the leads or "ploynas" in the arctic pack ice off Banks Island near the spot where *SEADRAGON* emerged from McClure Strait. Stefansson expressed his views to Sir Hubert Wilkins, the

late British explorer, who was with him at the time. Then in 1931, Wilkins became the first man to attempt to take a submarine actually under the ice. Wilkins had purchased the submarine O-12 from the United States Government for one dollar renaming her *"NAUTILUS."* After spending thousands of dollars on his submarine, Sir Hubert attempted futilely to penetrate the ice; but casualties to his aging sub forced him to turn back and abandon his scheme.

The Germans demonstrated during World War II that diesel powered submarines could carry out effective independent combat operations in the Arctic areas, in the fringes of the ice pack. They carried out various missions against the Russians in the Kara Sea. The U.S. enlarged on the German experiences with its own submarines between 1946 and 1953. It was found that in many ice areas the submarine can go where the surface ship cannot go since it can submerge, proceed under the ice, select an open area and come to the surface to charge its batteries.

These facts were used to begin ice pack studies. Following is a list of scientific studies conducted by submarines in ice areas since 1946:

Summer of 1946, U.S.S. *ATULE*, in the Kane Basin under the edge of the ice pack for 1,000 yards.

January 1947. U.S.S. *SEMRET* (SS-408) to the Ross Sea in the Antarctic. No dives were made under the ice.

Summer of 1947. U.S.S. *BOARFISH* (SS-327) conducted the first extended under-ice dives, covering a distance of about 30 miles during three dives in the Chukchi Sea in the Arctic.

Summer of 1948. U.S.S. *CARP* (SS-338) in the Chukchi Sea, experimented with methods of diving and surfacing in the ice.

August-September 1952. U.S.S. *REDFISH* (SS-395) in the Beaufort Sea remained under the ice nine hours, the longest under-ice dive recorded to that date.

August-September 1953. U.S.S. *REDFISH* (SS-395) in Beaufort Sea. (Joint exploration with Canada.)

August-September 1957. U.S.S. *NAUTILUS* (SS-(N)-571) conducted under-ice operations in the Greenland Sea and Arctic Ocean, spending 5½ days and proceeding 1,383 miles under the ice pack to within 180 miles of North Pole, a "furtherest North" for any ship. U.S.S. *TRIGGER* proceeded under the edge of the pack.

In August of 1958, *NAUTILUS* submerged in the Bering Strait off Alaska and four days later surfaced in the vicinity of Iceland. Practically parallel with *NAUTILUS'* west to east transit of the Arctic Basin was the submarine *SKATE's* twelve day exploratory cruise under the Arctic ice to the North Pole in the same month. *SKATE* entered and left the pack in the eastern Arctic. In March 1959, *SKATE* made a similar trip, but this time in the dead of winter. *SKATE's* second trip was significant in proving the feasibility of surfacing through the winter ice.

March 1959. U.S.S. *HARDER* and U.S.S. *TROUT* penetrated winter pack ice near Newfoundland and travelled 280 miles each beneath the ice, surfacing in ploynas to recharge batteries. The 280 miles distances were records for conventionally powered submarines.

In February of 1960, the nuclear submarine *SARGO* made the first entry to and exit from the Western approaches of the Arctic Basin. Her trip was made in mid winter, the most difficult time of the year for Arctic transits.

August 1960, *SEADRAGON* transits Northwest Passage and proceeds to the North Pole, making the first east-west transit of the Arctic Basin.

Industrial College of The Armed Forces

The following press release may be of interest to members who have not had an opportunity to see it in other publications:

"A graduate-level course offered by the Industrial College of the Armed Forces is available free of charge to qualified military and civilian personnel. Specifically, it is open to (1) military officers of all components of the Department of Defense and the Coast Guard, serving on active or inactive status in the grade of major or lieutenant commander or higher, and to (2) Federal employees with ratings of GS-11 or higher. A college education or its equivalent is highly desirable. Persons who do not meet these requisites but have compensating education and experience may be accepted for enrollment. All applicants are considered on their individual merits.

"Operating under the direction of the Joint Chiefs of Staff, the Industrial College conducts courses of study in the economic and industrial aspects of national security under all conditions and in the context of both national and world affairs, giving due consideration to the interrelated military, logistical, administrative, scientific, technological, political, and social factors affecting national security.

"The correspondence course is based on the 10-month resident course conducted by the College at Fort Lesley J. McNair, Washington, D.C., for selected military officers and civilian personnel to enhance their preparation for important command, staff, and policymaking positions in the national and international security structure. The correspondence version consists of 22 bound volumes organized into five integrated units of study: Background Information; Resources and Facilities; Processes in the Economics of National Security; Foreign Aspects of National Security; and Problems of National Security. It generally takes about one year to complete all units. A certificate of comple-

tion is issued to everyone who satisfactorily completes the full course, and a report to that effect is submitted to the appropriate authorities for inclusion in individual records. Reservists not on extended active duty may earn a total of 48 credit points for retention and retirement purposes.

"Qualified personnel are urged to consult the local education services or civilian personnel offices to obtain application forms and further information or to apply directly to the Commandant, Industrial College of the Armed Forces, Washington 25, D.C., ATTN.: Correspondence Course Division."

Controlled nuclear chain reactions in this low-power nuclear assembly will provide scientists and engineers at General Atomic Division of General Dynamic Corporation in San Diego with essential physics data for the development of the Maritime Gas-Cooled Reactor (MGCR).

The assembly's honeycomb aluminum frame contains more than 4,000 highly enriched uranium-aluminum foils as fuel. The unusual honeycomb design permits great flexibility in arranging the fuel and moderator to achieve desired nuclear compositions in studying the core arrangements for the reactor.

The MGCR system, being developed by General Dynamics' General Atomic and Electric Boat Divisions for the U. S. Atomic Energy Commission and the Maritime Administration, will combine a high temperature gas-cooled reactor with closed-cycle gas turbine power machinery.

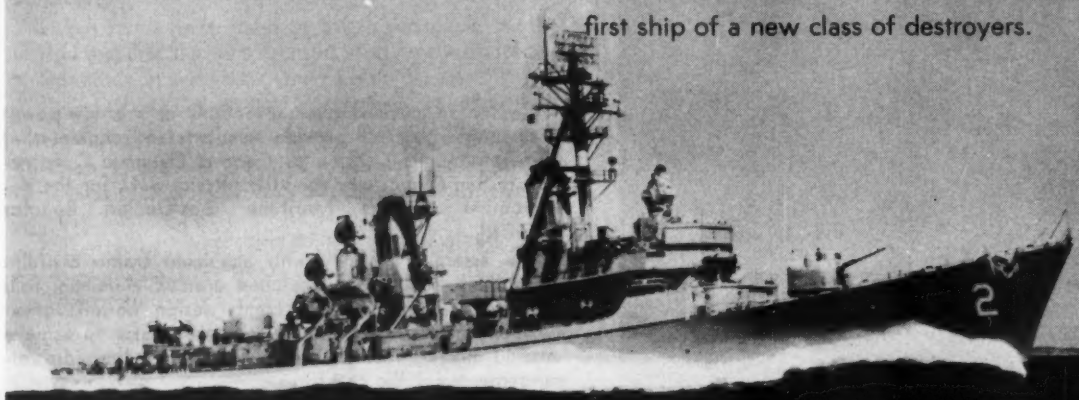
To left, a General Atomic staff member loads a fuel channel containing uranium-aluminum foil into the assembly.

—General Dynamics Corporation

ANOTHER FIRST FOR BATH!

U.S.S. CHARLES F. ADAMS (DDG2) —first of a new class of guided missile destroyers to join the Navy. Named for one of America's greatest yachtsmen and a former Secretary of the Navy, the CHARLES F. ADAMS is 437 feet L.O.A., and displaces 4500 tons fully loaded. She carries Asroc and the Tartar surface to air missile.

The CHARLES F. ADAMS continues Bath's long record of delivering the first ship of a new class of destroyers.



BATH IRON WORKS

Shipbuilders & Engineers

BATH, MAINE

CAPTAIN T. B. OWEN, USN AND MR. J. B. ALFERS

MARINE APPLICATIONS OF PLASTICS

THE AUTHORS

Captain Owen was commissioned in the Navy in 1940 upon graduation from the University of Washington where he received a Bachelor of Science degree in Chemical Engineering. After four years of service afloat during World War II and a brief tour in the Bureau of Naval Personnel, he participated in the Navy officers' postgraduate training program. In 1950 he received the degree of Doctor of Philosophy in Physical Chemistry at Cornell University. After a year's work at the University of Amsterdam he was designated as an Engineering Duty Officer. He then returned to the United States for duty in the Naval Sciences Division of the Office of Naval Research. He was then transferred to the Long Beach Naval Shipyard where he served successively as Assistant Repair Superintendent and Production Control Superintendent. At the conclusion of this tour he was assigned to the Bureau of Ships as Head of the Materials Development Branch. He is now Director, Applied Science Division of the Bureau.

Captain Owen holds the Silver Star Medal, Bronze Star Medal, the Navy Unit Commendation and other area service awards. He is a member of the American Chemical Society, Tau Beta Pi and Sigma Xi.

Mr. Alfers graduated from Kansas State University with a degree in Electrical Engineering. He worked for several years with the Rural Electrification Administration on operation and maintenance of Rural Electric distribution systems. For the past 18 years, he has worked in research and development and standardization of plastic and dielectric materials for the Bureau of Ships. At the present time, he is Acting Head of the Section for Polymers, Fibers and Packaging of the Material Development Branch.

Mr. Alfers recently received a Master's degree in Engineering Administration from George Washington University. He has received the Distinguished Civilian Service Award from the Secretary of the Navy and the Executive Award from the Reinforced Plastics Division of the Society of the Plastics Industry. He is a member of the Society of Plastic Engineers, the American Institute of Electrical Engineers, the Society of the Plastics Industry and the the American Boat and Yacht Council.

DEFINITIONS

PLASTICS GENERALLY are materials made up of carbon containing molecules that have hooked themselves together in chains to form what we call organic high polymers. In some stage of production, the materials are capable of being formed or shaped usually through the action of heat and pressure. In use, the polymers are often combined with reinforcing, flexibilizing, coloring, or stabilizing materials to adapt them to a large variety of uses. The terms resin, plastic, and polymer are used interchangeably

to designate the principal high molecular weight component of plastic materials. The term "resin" was originally used for natural gums. "Polymer" is derived from the Greek word "Mer" meaning part or segments—hence "polymer" meaning many parts (i.e., high molecular weight).

HISTORY

Development

Many people think of plastics as very new or recent materials. However, recognition of polymers dates back as far as 1831 when the chemist Berzelius first identified styrene. The first useful application of artificial plastics resulted from the work of the Hyatt brothers in 1868. They won a prize offered by the French Government for the development of a material to replace ivory used in billiard balls. The Hyatts discovered that the addition of camphor to cellulose nitrate would produce an ivory-like material. In 1907, Dr. Baekeland commercialized phenol-formaldehyde resins later called Bakelite. In the 1930's great strides were made in gaining an understanding of the basic chemistry of polymers. It was in this period that the foundation was laid for the development of the variety of materials we know today such as acrylics, vinyls, polystyrene, nylon, melamine, polyesters, epoxies, and others. Since 1940 the potentialities of plastics as regard strength, service temperature, electrical characteristics, and other properties have been greatly expanded through development of new materials.

Production

From the modest production in 1934 the industry has grown to a 1958 level of 4.5 billion pounds a year. This is comparable to current aluminum and rubber production. It is predicted that the output of the plastic industry will rank 4th among basic materials by 1975. It would be exceeded only by the production of steel, wood, and glass. Family use of plastic materials has increased by a factor of 10 in the last 15 years. In the next five it is expected to double. In 1935 a household refrigerator used one pound of plastic; in 1956 it contained twenty-two pounds. We have had the Stone Age, the Wood Age and the Iron Age. This era might well be called the Age of Plastics.

Industry sources

Plastics as received by the consumer are usually the products of a resin manufacturer and one or more processors or fabricators. The resin manufacturer (Dow, U. S. Rubber, du Pont, Carbide, Goodrich, and Monsanto are among the larger ones) draw their materials from several sources in the petroleum, coal, and chemical industries. Resins may be liquid or solid. They are usually processed and compounded with other constituents such as pigments, lubricants, stabilizers, or fillers in order to give them certain desirable handling or use characteristics. The resulting materials are ready for conversion by press, extruder, or other mechanical devices into useful forms such as sheet, pipe, tape, and other end-items.

TABLE I—*Classification of Plastics*

Basic Sources	
Natural	— Rosin
Synthetic	— Polyethylene
Raw Materials	
Cellulose	— Cellulose acetate
Coal tar	— Phenolic
Petroleum	— Polyethylene
Chemical Reactions	
Addition	— Polyethylene
Condensation	— Phenolic
Physical Groupings	
Thermoplastic	— Polyethylene
Thermosetting	— Phenolic
Chemical Classes	
Vinyl	
Ethylenic	
Epoxies	
Polyester	

CLASSIFICATION

Plastics may be classified in several ways. (See Table I.)

Raw material

They may be classified by the raw material from which they are derived. For example cellulose acetate is a cellulosic; coumarone indene a coal tar resin; and polyethylene a petroleum derivative.

Material source

They may be grouped by source—for example natural or synthetic. The major portion of the plastics produced today are synthetic as opposed to the use of some naturally occurring materials such as resin.

Chemical reaction (Figure 1)

Plastics may be described by the chemical reaction required to transform the base material (monomer or single part) into the higher molecular weight polymer. The condensation reaction, for example, involves the evolution of by-products such as water or ammonia. The addition reaction is a simple case of monomer addition to form chains without by-product formation.

Chemical class

These materials may be classified by their chemical constitution such as vinyls, cellulosics, poly-

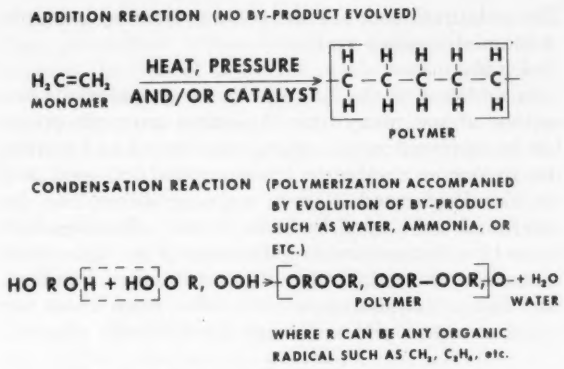

ADDITION REACTION (NO BY-PRODUCT EVOLVED)
$H_2C=CH_2$
MONOMER
HEAT, PRESSURE
AND/OR CATALYST
POLYMER
CONDENSATION REACTION (POLYMERIZATION ACCOMPANIED BY EVOLUTION OF BY-PRODUCT SUCH AS WATER, AMMONIA, OR ETC.)
HO R O H + HO O R, OOH
OROOR, OOR–OOR
POLYMER
$+ H_2O$
WATER
WHERE R CAN BE ANY ORGANIC RADICAL SUCH AS CH_2, C_6H_4, etc.

Figure 1. Classification by Chemical Reaction.

esters, and epoxies. There are at least fifteen such broad classifications. Each of them is a highly complex and specialized field. There are resin chemists who will spend their whole careers in the study of certain vinyls. Knowledge of the chemical class of a particular resin is of value to the plastic technologist because it will often permit him to draw general conclusions as to properties, processing, and type of adhesive to be used.

TABLE II—*Physical Groupings*

THERMOPLASTIC	THERMOSETTING
Acrylic	Phenolic
Cellulose Acetate	Melamine
Polystyrene	Urea
Polyamide (Nylon)	Epoxy
Polyethylene	Silicone
Polytetrafluoroethylene (Teflon)	Polyester
Polyvinylchloride	Alkyd

Physical groups (Table II)

Possibly of most interest to the fabricator of plastic parts is the classification of the materials into thermoplastic and thermosetting compounds. This grouping will indicate generally the processing or fabrication procedure applicable to a specific material.

1. *Thermoplastics*

These are materials which soften under application of heat, are formed or molded in this condition, and then are allowed to harden on cooling. They can undergo this process repeatedly. Wax is a simple example. It melts when heated, can be cast into a shape while warm, and will harden when cool. It can subsequently be remelted and cast. In this class are plastics such as vinyl chloride, polyethylene, polystyrene, cellulose acetate, nylon, and teflon. They are used to make such items as garden hose, shower curtains, furniture upholstery, pipe, toys, wall tile, and hoola hoops.

2. *Thermosetting compounds*

These may be liquid or solid in original state but can be formed or converted to infusible solids through the use of heat and pressure. Once converted they cannot be reworked. Subsequent application of heat causes charring and decomposition. One finds phenolics, ureas, melamines, polyesters, and epoxies in this class. These materials are used in telephone handsets, electrical boxes, receptacles, buttons, table tops, in combination with glass fibers in parts of certain automobile bodies, and a host of other industrial items.

PROCESSING

Plastics are converted into finished products by a variety of methods.

Molding

Molding is usually accomplished by forming the plastic article in a closed die using controlled temperatures and pressures. Such molds may be operated in a press for opening and closing the die and for applying pressure. They are often intricate and very costly. Thermoplastic materials, which must be cooled in order to harden, are usually injection molded. In this process the material is heated and softened to the point where it will flow. It is then quickly forced into a cold mold under high pressure (sometimes 20-25000 psi). It fills the mold cavity, cools, and hardens almost instantaneously. When one considers that up to 30 molding cycles may be completed per minute in a completely automatic machine, and that the mold may be multicavity (i. e., capable of producing several parts at once), he can appreciate that this is truly a high speed production method. Thermosetting materials, which harden after being heated, are compression or transfer molded. This involves introducing material into a hot mold and holding it under pressure for the time required to complete "cure" or hardening. The time required to complete the cure is the limiting factor in production output. There are some special, fast cure materials which do permit cycles of ½ minute or less in automatic presses.

Extrusion

Extrusion is a process usually limited to thermoplastics. It involves a continuous process for heating and masticating the plastic and then forcing it into the desired cross-section. Pipe, tubing, tape, fibers and cable insulation are typical examples of extrusions. The extrusion process is the fastest production technique in terms of pounds per hour but is limited to continuous production of uniform cross-sections.

Casting

Casting is a process in which liquid resins are poured into a mold cavity. They may be thermoplastic, in which case the resin is poured hot and permitted to cool. More usual, however, the resin is of a thermoset type which is cured by applied heat or by chemical activation. Little or no pressure is used in a casting operation. Encapsulation of electronic circuits is an example of casting.

Laminating

Laminating is the process of building up materials from thin layers. The method is usually applied to the makeup of sheets of plastic impregnated reinforcing materials such as paper or cloth. In some instances the laminating is done in large multiplaten presses under several thousand pounds per square inch of pressure at controlled elevated temperatures. In other cases, laminating type operations are carried out to produce large complex shapes where high pressures and temperatures are not used. Certain thermosetting resins such as polyesters, epoxies and phenolics can be used in combination with high strength reinforcing materials, (usually glass fibers in various forms such as unidirectional filaments, woven cloth or random mats) to produce laminates having varied strength characteristics. Some of these resins can be converted from liquids to solid, without application of heat or pressure, by chemical reactions induced by addition of chemical activators and catalysts. Formica and Conolite are trade names for typical high pressure laminated sheets, rods and tubes. Reinforced plastic boat hulls are an example of low pressure lamination.

Blowing

Blowing is the term applied to the formation of certain thermoplastic items such as bottles and containers. The methods and machinery are very similar to that used for glass articles.

Hot forming

Hot forming is a process where a sheet of plastic is made soft and flexible by heating, then placed over or in a form and made to conform, usually under either vacuum or light pressure. On cooling, the sheet retains the shape of the form. This process is used in fabricating a great variety of thermoplastic materials. It may be applied to a few thermosetting plastics by forming them before the complete state of cure or hardness is reached. Many containers for packaging are formed in this manner.

Foaming

Foaming is the process in which a light weight cellular plastic is formed. Foams can be produced having densities ranging from 1 to 30 lbs. per cu. ft. with varying degrees of rigidity or flexibility. They are used in such diverse applications as thermal insulation, buoyancy, and shock absorption. Thermoplastic foams are usually provided in the form of planks, blocks, slabs, or logs. More recently, pellets of polystyrene containing a "blowing" agent have become available. These may be poured into a cavity and expanded by jets of live steam. Thermosetting foams are capable of being foamed-in-place. They are provided in liquid form as two or three component systems. After the components are mixed, a chemical reaction takes place which simultaneously causes foaming and curing or hardening of the resin. The polyurethanes are the most promising example of foamed-in-place resins.

Assembly

In addition to the basic processing operations described above, many uses of plastics are made possible by application of cutting, machining and fastening processes similar to those applied to wood and metals. Preformed sheets, rods or tubes can be machined and joined by bolts, rivets, adhesives, and some by a form of welding. Because of the individual materials characteristics, the machining, handling and design requirements will differ from those for wood or metal and will vary for different plastics.

MARINE USE

Selection

1. *General*

There is a myriad of plastic materials available for a wide variety of uses. The flexibility inherent in their properties and chemical constitution offers a much greater variety for selection than in the case of wood or steel. Plastics are of interest to the Navy not as substitutes but rather as materials having their own specific and desirable characteristics which should be considered in the design, construction, and repair of ships and components. Each specific formulation has a unique combination of properties. Knowledge of these is essential when specifying a particular material for application.

2. *Advantages*

Most all plastics offer certain similar benefits which account for their wide usage:

a. Light weight
b. Insulating qualities
c. Non-magnetic
d. Ease of fabrication
e. Cost
f. High strength
g. Design flexibility
h. Available from domestic raw materials
i. General corrosion resistance
j. Appearance

3. *Disadvantages*

On the other hand these advantages may be offset by disadvantages common to many plastics:

a. Fire resistance
b. Gaseous combustion products
c. Low rigidity
d. Cost
e. Heat resistance
f. Weatherability
g. Corrosion resistance

4. *Bureau policy*

The Bureau of Ships has not chosen to differentiate plastics from other materials routinely used in Navy ships. It is felt that wider application of plastics is possible and desirable. Engineers and

service personnel must become more familiar with their properties. There has been some inclination to resist the use of these materials presumably because of their combustibility. In many cases this is apparently used as an excuse to continue to specify "tried and true" materials which are more commonplace and with which more people have had experience. Few people realize the permissiveness of Chapter 88 of the Bureau of Ships Manual which lists a series of plastics that may be employed when fire hazard is a consideration. Many more plastics can now be added to the list as more data become available. There is a conscious effort now underway in the Bureau to overcome the inertia and lethargy regarding the use of plastic materials. A more constructive approach is being dictated wherein the material best suited to the application at hand from the standpoint of cost and performance should be specified regardless of whether or not it be wood, metal, elastomer, fiber, or plastic.

General Uses

The broad application of plastic materials to current shipboard use may not be fully appreciated. Vinyl and alkyd paints, plastic deck covering materials, plastic electrical insulating materials, and foamed plastic life rings are in common use. It is possible that they are not recognized since they do not appear in massive or readily identifiable form. Reinforced plastic boats, nylon mooring lines, nylon and plastic coated tarpaulins are items of outfitting and supply. Minecraft carry plastic floats and dan buoys. Most of the Bureau's interests appear to lie in the application of four different plastic forms namely: dielectrics, thermoplastics, foams, and reinforced materials. The last three categories are of particular interest. There follows some discussion of the applications of these materials to ships of the Fleet.

EXAMPLES OF CURRENT USE STRUCTURAL

Submarine fairwater

In early 1953 a conning tower fairwater of aluminum was removed and one of reinforced plastic was installed on the USS *Halfbeak* (SS 352). The aluminum structure had deteriorated from the corrosion in service. Reinforced plastics although proven in boats and other semi-structural uses had not previously been applied in such a large unit or considered for the severity of service as an operating submarine would encounter on the high seas. Laboratory test and engineering judgment indicated, however, that the structure could be designed, constructed and installed and expected to perform in a satisfactory manner.

This structure was built by a plastics fabricator and partially preassembled at the producing plant. Several large subassemblies were shipped to the Philadelphia Naval Shipyard where they were joined and installed through the joint efforts of the contractor and the shipyard. (Figure 2.) It is made up of plastic plates and stiffeners with sections joined by adhesives and bolts. The plating was about ¼ inch thick with frames 4 inches deep. The entire unit weighed 7400 pounds or about the same as the aluminum structure removed from the same ship. In July 1953, the first glass reinforced plastic structural unit went to sea.

Figure 2. Plastic Fairwater

After two and a half years of service the Commander, Submarine Forces Atlantic Fleet, stated "The ability of the plastic fairwater to withstand the stresses occurring during a hurricane is most encouraging. No more conclusive evidence of reliability appears to be necessary." Last month the USS *Halfbeak* was inspected in the Philadelphia Naval Shipyard. After five and a half years, the material looks as good as when it was installed. Under the paint, the original mold finish is present, there are no delaminations, the bolts are tight, and it appears good for an indefinite number of years of future service.

The initial success of the fairwater on the USS *Halfbeak* led to consideration of the replacement of other aluminum units as they become uneconomical to repair. In November 1956 a similar plastic fairwater was installed on the USS *Grampus* (SS 523). During May and August 1957 units were installed on the USS *Cutlass* (SS 478) and USS *Irex* (SS 482). The three latter fairwaters were of a

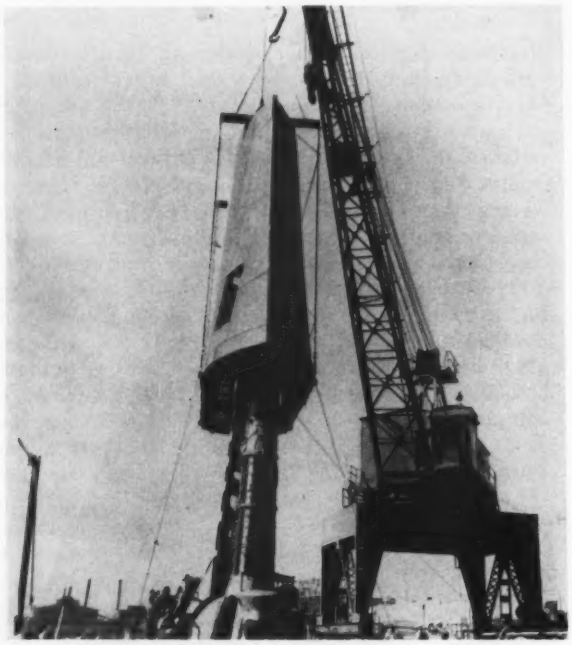


Figure 3. Plastic Fairwater.

Figure 4. Plastic Fairwater.

different design and configuration. The changes in design was made to provide a higher bridge, to provide for interchangeability on submarines of the *Guppy II* class, and to reduce the cost of simplifying the molds (Figures 3 and 4). These considerations resulted in a fairwater weighing about 9000 pounds. It was assembled from vertical panels each 24 inches in width by 30 feet long. Each included a strip of vertical plating and an integral **Z** frame. The fore and aft contoured sections were separately molded as in the *Halfbeak*. These vertical panels could be trimmed to reduce both the length and width to fit different ships of this class.

The experience with these structures has been quite satisfactory. In some of the forward panels, inadequate strength has been found. Modification to these weaknesses have recently been made and it is expected that these will be maintenance free fairwaters for many years. A few words about the cost of these structures may be of interest. Costs which are truly comparable and reasonably accurate are difficult to obtain. Installation costs vary among yards. Some of the plastics units are of the larger high bridge design. All of the metal ones replaced were of the low bridge design. In addition there was little experience in the shipyards in handling plastic —a fact contributing to high installation costs compared to metals work.

The USS *Halfbeak*, requiring original design work, molds and installation by workers unfamiliar with the materials and techniques, cost about $300,000. This compares with the cost of $125,000 to replace an aluminum unit. The last fairwater installed on the USS *Irex* at Philadelphia Naval Shipyard cost about $128,000. This included $52,000 for the plastic panels and other plastic items. The remaining $73,000 represents labor costs for removing the old aluminum unit and for assembling and installing the plastic one. Estimates for future orders of 5 to 10 ship sets are $40,000 each for the plastic items, to which costs of the shipyard must be added.

Submarine superstructure

In 1953, about 100 feet of reinforced plastic superstructure both plating and framing was installed on the USS *Croaker* (SSK 246) on the forward part of the ship. Breakage was experienced because of the contacts with tugs and docks. Changes in depth caused the plastic to flex and to emit crackling noise. The design was marginal. For these reasons, it was removed. Further study of the material and design used gave indications as to how to eliminate the noise in superstructure installation. A smaller section of superstructure plating from frames 43 to 47 was installed on steel frames on the USS *Guavina* in early 1956. This installation has been completely successful. It weighed 1543 pounds in comparison to the conventional steel and wood construction of 1817 pounds. (Figures 5, 6, and 7) The favorable re-

Figure 5. Plastic Superstructure (Top View).

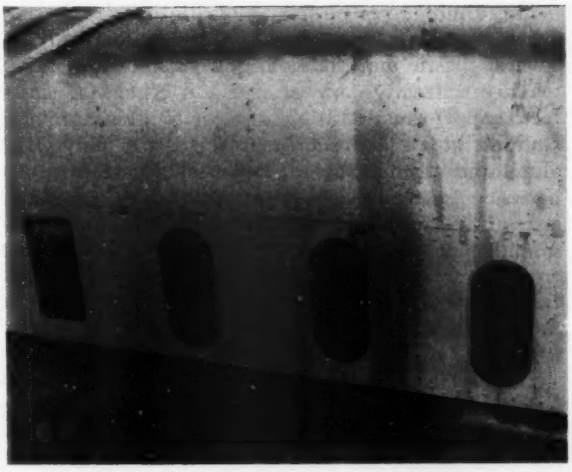


Figure 6. Plastic Superstructure (Exterior).

Figure 7. Plastic Superstructure (Interior).

sults of this installation have led to consideration of new installations in the near future using both steel and reinforced plastic frames.

Sea cabin

Reinforced plastic construction is of interest in topside applications for saving weight (or to obtain greater strength for equal weight) and minimum maintenance. Aluminum construction has often been used but it has obvious disadvantages with regard to resistance to marine atmosphere and to the requirement for isolation from adjacent dissimilar metals in order to prevent electrolytic action. In addition, the design allowables are very low for some alloys when welded.

A steel sea cabin, approximately 9'-0" x 7'-0" x 6'-5" high was replaced by a plastic honeycomb construction on the USS *Southerland* (DDR 743) early in 1955. (Figures 8 and 9) The sides, overhead and deck were made of separate panels which consisted of a light weight phenolic impregnated paper honeycomb core (which weighed 4½ lbs. per cu. ft.) sandwiched between glass reinforced plastic faces. This construction was used in order to obtain the greatest amount of panel stiffness at the lowest weight. The plastic facings were $\frac{3}{16}$" thick on the outside (to provide greater impact resistance) and ⅛" inside. The overall sandwich thickness was 2" for roof and floor and 1¾" for sides. The structure was designed to withstand wind loads up to 130 miles

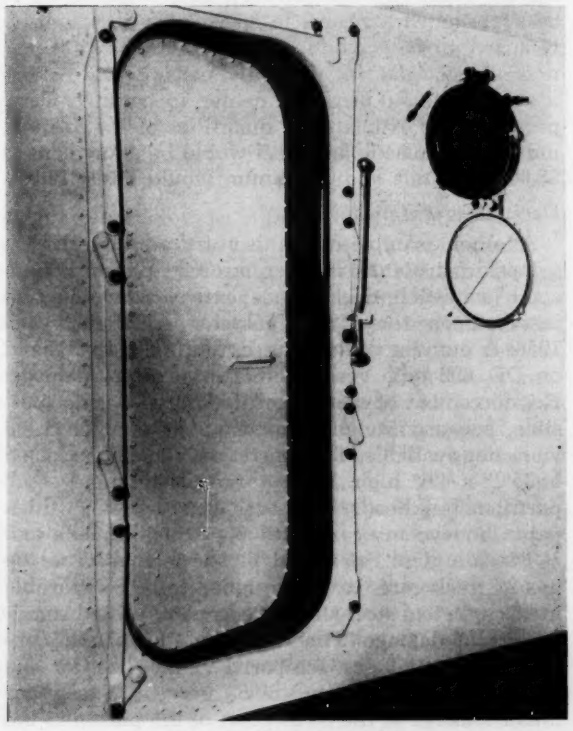


Figure 8. Plastic Sea Cabin.

Figure 9. Plastic Sea Cabin.

per hour. No additional thermal insulation was used because honeycomb panel was found to be the equivalent of 1" thick fiberglass blanket. Weight of the steel cabin replaced was 6000 pounds as compared to 2,085 pounds for the plastic unit. Estimates on a comparable aluminum cabin showed that the cost would be about 10 percent lower but the weight would run 1200 pounds higher than the plastic construction. The cabin was inspected after two years in service and found to be in excellent condition. In addition to achieving a 65 percent weight saving, service experience has shown plastic construction to be superior with regard to habitability. It has been reported to be cooler in hot climates, has a lower noise level, and its flat bulkheads provide more usable space and present a neater appearance. Comparative cost estimates in quantities of six or more indicate the plastic and steel would be equivalent at $8,000 per unit and aluminum would cost $10,000.

Deckhouse extension

Another example of the use of these materials in a topside structure is the reinforced plastic honeycomb sandwich deck house extension which was installed on the USS *Fechteler* (DDR 820) in 1956. A number of deckhouse failures had occurred on DD 692 type vessels because of storm damage. Reinforcement of these steel structures was not possible because weight and moment compensation were not available. The plastic deckhouse extension is 35'0" x 4'6" high. It has three plastic honeycomb partition bulkheads. The sides consist of 3½" thick paper honeycomb core with $\frac{3}{16}$" thick outside and ⅛" inside glass reinforced plastic facings. The top has 2" thick core. It was designed to be comparable in strength to a steel structure, capable of withstanding storm damage. The weight of the plastic construction is 2400 lbs. compared to 7500 lbs. for one of steel, a weight saving of 68 percent. Except for minor leakage at the connection of the plastic to the main deck house, service has been satisfactory. Estimated cost in quantities of six or more is $15,000 per unit. This is equal to the cost of an aluminum structure which would not be as structurally adequate.

Joiner bulkheads

(a) General: In recent years a number of plastic materials have been used in experimental joiner bulkheads and partitions. Honeycomb cored plastic faced panels, corrugated sheets of polyester glass laminates and of acrylics, vinyl sheet covered aluminum and plastic tile have had service trials. These have been evaluated in comparison with aluminum, both painted and unpainted, and corrosion resistant steel.

In general, the plastic approaches have been more expensive than the older and more conventional materials. Often, however, costs are based on the experimental installation in the new materials. Older materials and their fabrication and installation problems are more familiar to shipyards.

If the major restriction to plastic bulkheads and partitions that of resistance to fire were disregarded, several plastic materials offer promise of low maintenance, attractive appearance and otherwise satisfactory performance at a cost close to aluminum and stainless steel. One such material is the vinyl clad aluminum sheets. Several years of satisfactory experience is available. The material does not stain, is easily cleaned and remains bonded to the aluminum. This product is fabricated in the same manner as sheet aluminum. The vinyl sheeting is applied to the aluminum sheet and is tough and flexible enough to withstand the various sheet metal forming operations.

The corrugated sheets of glass reinforced polyester and of acrylic resin show some promise. Both of these materials require somewhat special fabrication and installation techniques. They are supported by conventional aluminum stanchions. In shower stalls, the reinforced polyester sheets have been found to collect a soap film which is found to be hard to remove. This results in a dull and soiled appearance. The acrylic sheets have held up well in appearance but some have broken by sharp blows. The material is not nearly as strong as the glass reinforced sheets. Both of these materials should be cheaper on an installed basis than the corrosion resistant steel. Further work will be needed to overcome the indicated deficiencies.

(b) Installations: In 1956 comparative installations of joiner bulkheads made of vinyl sheet covered aluminum, paper honeycomb faced with Formica laminate, and paper honeycomb faced with reinforced polyester laminate, were made on the LSD 34. The panels were made up by the Douglas Aircraft Company and installed by the Ingalls Shipbuilding concern. Installed costs were $4.00 per sq. ft. for the aluminum and $12.00 per sq. ft. for the honeycombs. The latter were ½" thick by 3' wide

and were joined by H and channel sections of glass reinforced polyester resin with radius and right angled sections of aluminum. They weighed one pound per square foot. The installation has not been reported.

Crews washrooms in the USS *Otterstetter* (DER 244) were used for a comparative test of:

Corrosion resistant steel	Acrylic sheets
Bare aluminum	Plastic wall tile
Painted aluminum	Porcelain aluminum wall tile
Vinyl sheet covered aluminum	Paint
Corrugated glass reinforced polyester sheet	Vitroglass

Installations were made by the Portsmouth Naval Shipyard.

The materials were inspected in 1957. Most successful were corrosion resistant steel, vinyl sheet covered aluminum and chlorinated rubber base paint.

Sonar domes

Interest in reinforced plastics to house sonar transducers developed as a result of certain advantages which material investigations showed plastics had over rubber and steel domes. Plastic sonar domes can be used to lower topside weight, to reduce the effects of water and hull generated noises, to minimize corrosion problems, to reduce construction time, and to achieve lower costs in production due to ease of fabrication into complex shapes. Acoustical tests of plastics have indicated that good transmission can be achieved at various frequencies especially where steel thicknesses would have to be excessive. Another advantage is the fairness of the surface which can be obtained with plastics.

Early in 1954 an experimental BQR/3A dome was built by the David Taylor Model Basin. This dome showed considerable improvement in tracking while operating at snorkel depth. This dome was tested by the Naval Research Laboratory at frequencies up to 60 Kc with excellent results. As a result, the Bureau procured fifty-four of these domes from Lunn Laminates, in 1955. (Figures 10 and 11) In four years only one failure was reported. However, no other procurements of these domes were made since the transducers these domes housed became obsolete.

This early experience led to the installation of a ribless conformal nose dome on the USS *Albacore* in 1955. Service performance has been excellent with no failures.

In November, 1955, the Bureau authorized Electric Boat to procure a plastic bow dome with plastic ribs for the *Nautilus*. Our first experiences with this application were rather unhappy. Three domes failed and had to be replaced in rapid succession. As is often the case, tightly scheduled operational requirements made it impossible to do much more than

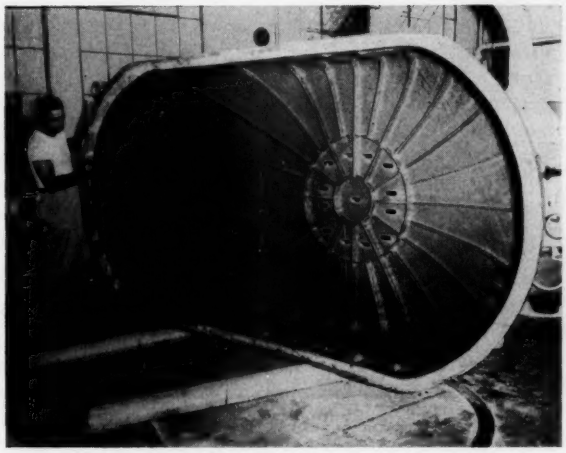


Figure 10. Plastic Sonar Dome.

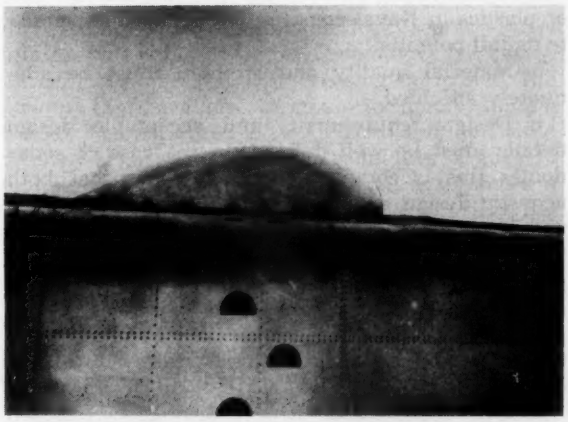


Figure 11. Plastic Sonar Dome.

replace each dome, as it failed, with another much similar one. As a result of the last failure, in December 1957, however, a composite dome of steel trusses and plastic skins was installed on the *Nautilus* just prior to its history-making voyage under the North Pole. (Figure 12) Thus permitting plastics people to brag that they were there first! This dome has proven satisfactory both structurally and acoustically. A dome of similar construction has since been installed on the *Skate*. The *Swordfish* also has a plastic bow dome.

In May 1956, installation of plastic bow domes on the SSN 580 class was authorized. It is believed that there are five still installed. It must be stated that, due to the highly complex nature of the entire sonar system, the fortunes of plastic vs. steel construction have not been fully resolved and may not be for some time. Plastic construction does, however, seem to offer interesting possibilities for sonar dome application at present.

Experience with the *Nautilus* and other bow

Figure 12. Plastic Sonar Dome.

domes has pointed up some important factors, however, which must be carefully controlled if the use of plastics in Naval construction is to be expanded to its full potential.

a. Material quality and strength must be adequately specified.

b. Design requirements and acceptable design details must be well defined. In the case of sonar domes this is complicated by the fact that both acoustic design and structural design are involved and it is not always a simple matter to reconcile them. For example, it is presently accepted that plastic framing is unsatisfactory from the acoustic standpoint.

c. Careful inspection is necessary to assure that the reinforced plastic structure conforms to all requirements.

d. Reinforced plastic structures must be handled and installed by personnel trained in working with such materials. Damage during installation has contributed to failures.

e. The ships force also must be given training in regard to maintenance and repair of reinforced plastic.

Radar tower

Consideration has been given to the construction of a plastic tower 85 feet high for mounting certain radar equipment on the very top of the CAG-1. (Figure 13) This tower would be composed of three platforms tapering from 50 feet square at the base. The tower might weigh 60,000 pounds and would support 12,500 pounds of equipment at the three levels.

Such a tower is being considered because of the low dielectric loss, low dielectric constant and structural properties of the glass reinforced plastic materials. The low dielectric characteristics would enable the antenna to be located within the structure, rather than exterior to the structure as is common with metal supports. The enclosing and supporting plastic structure would be similar to a radome. In addition to the structure being electrically transparent, it would afford protection of the electronic equipment from the normal environmental conditions.

This proposed tower is considerably larger than anything previously built of reinforced plastic. Many conditions as listed below represented new and more severe service conditions than encountered in previous plastic structures:

(a) Battle damages
(b) Roll and pitch accelerations
(c) Stack gases
(d) Ice and wind loads
(e) Salt and soot removal

Two basic approaches are being considered. The first is that of a completely enclosed structure resembling a series of large radomes. The other is a truss structure supporting the platforms. The latter would consist of a series of vertical legs or columns. It would not provide complete protection to the equipment but would reduce the problem of resisting windage and blast damage.

Although the preliminary design study has not been completed, the structure is considered feasible and practicable of reinforced plastics. This conclusion is based on the basic knowledge of the material and experience with other shipboard plastic structures over the past five years.

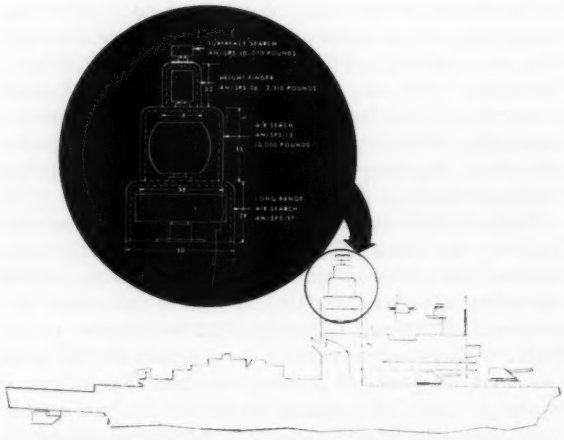


Figure 13. Proposed Plastic Radar Tower for CAG 1.

PIPING

General

The self extinguishing characteristic and the relative high levels of strength and toughness of the high impact type rigid vinyl chloride resins have attracted considerable interest. Accordingly, considerable effort has been expended to develop these resins in sheet, tube and molded forms to a point of usefulness for Naval ships. Materials were examined, deficiencies were corrected through coopera-

tive work with the producers and satisfactory products and standards obtained. These materials have found use in the ABC washdown system (Figure 14) as pipe and fittings and in one minesweeper as ventilation ducting.

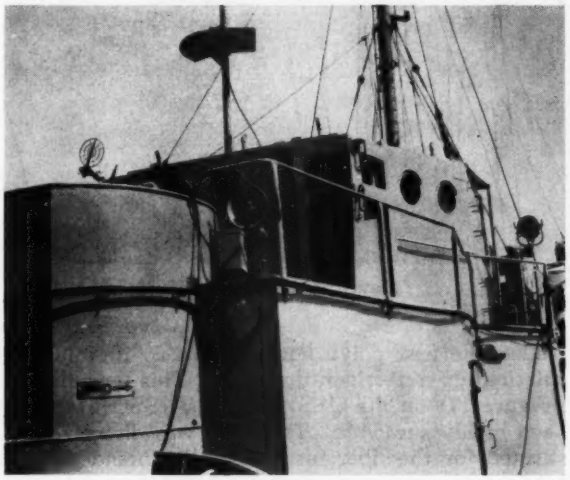


Figure 14. Wash-Down Piping.

Plastic Ventilation Ducting

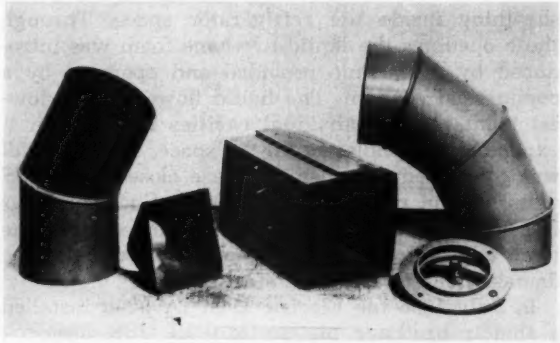


Figure 15. Plastic Ventilation Duct Sections.

Plastic materials have certain characteristics which make them adaptable to ducting. Of most importance is corrosion resistance especially in connection with corrosive vapors in battery systems. In general plastics are lighter than metals. The low rigidity, however, offsets most of the potential weight savings in a ducting system. The non-magnetic property is of value in minesweepers. Less noise transmission is expected to be an advantage of plastic over metal ducting.

Projects to investigate the possibilities of plastics in ducting were pursued by several naval activities and by private contractors. Material thicknesses required, means of fabrication, assembly and installation, and relative costs were established.

Two basic types of materials were investigated—rigid, high impact vinyl chloride sheets and moldings of glass fiber reinforced polyester. The latter material was not carried beyond a preliminary state because it is not fully adaptable to most shipboard ducting problems. The materials cannot be post formed on the job into the numerous shapes required, standard shapes are not available and the problem of molding ducts to the required configurations is uneconomical.

The rigid vinyl chloride material is a thermoplastic with adequate ductility for forming and adequate fire and heat resistance for certain applications. It was therefore carried to a ship installation.

During the spring of 1957, the Consolidated Shipbuilding Company installed about 15 per cent of the ventilating ducting made of the vinyl sheet material in the wooden minesweeper *Bittern* (MHC 43). Since the installation was experimental many variations were used. Thicknesses from .050 to ¼" were employed. Joints were made of adhesives, hot air welding, rivets, bolts and lock seams. Panel stiffness was obtained by the fastening of transverse stiffening members and by creasing the panel. The various configurations common to metal ducting systems were formed of both cold and hot vinyl sheet by sheet metal forming techniques. Figure 15 shows some of the items used. Figure 16 shows a mock-up prepared in advance of the ship installation.

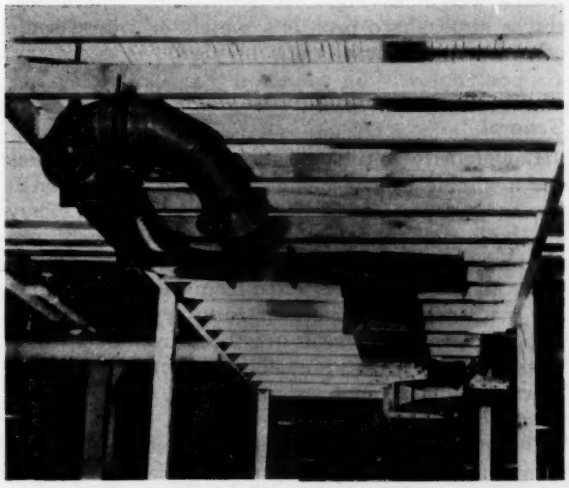


Figure 16. Mock-Up Plastic Ventilation Duct.

Another vinyl sheet installation was made by the San Francisco Naval Shipyard on an open tank battery system on USS *Spinax* (SSR 489). This system was produced by methods similar to those used by Consolidated Shipbuilding Company.

At the time the MHC 43 installation was planned, the relative weights and gauges for various round duct sizes of vinyl sheet and aluminum were as shown in Table III.

TABLE III—*Non Watertight Ducts*

VINYL SHEET			ALUMINUM	
Thickness Inch	Weight lbs/sq.ft.	Duct. Dia. Inches	Thickness Inch	Weight lbs/sq.ft.
.050	0.42	6	.034	.46
.063	0.54	8	.040	.58
.094	0.79	10	.040	.58
.094	0.79	12	.051	.74

The actual cost of the plastic ducting installed in the *Bittern* was roughly double that of the equivalent amount of aluminum ducting. The labor was about 60 per cent of the total installed cost and the material 40 per cent. It is estimated that future installations of vinyl plastic duct system would be about 40 per cent greater than a comparable aluminum system. This reduction is estimated to be possible mainly because of the experience gained in the first installation. Lower material cost of about 20 per cent since this installation also contributes to the expected future cost.

Rigid vinyl ducting will likely be more costly than metal for some time. The materials are more expensive to begin with and there is very little experience in naval or private shipyards with their use. The fabrication of vinyl sheets into ducts is so nearly the same as with sheet metal that no substantial savings are expected in the fabrication operation.

Such ducting, however, may be very worthwhile where weight savings are essential or where corrosive atmosphere prohibits metals or where some other unique characteristic of plastic is necessary.

INSULATING MATERIAL

General

Low density cellular plastic products called foams are available or are being developed. Their densities range from 1 to 30 pounds per cubic foot. They are both rigid and flexible. In some the cells are interconnected as in a sponge and in others essentially all the cells are isolated from each other. They are made from a variety of resin types. The most important to the Bureau are those from such thermoplastics as polystyrene, vinyl chloride and such thermosetting resins as urethanes, epoxies and phenolics.

Our program is principally for the study of promising material developed by commercial concerns to develop engineering data of value for specific purposes in ship construction, inspection methods and application techniques. These studies are applicable to present and proposed uses for buoyancy, thermal and acoustical insulation, energy absorption and void filling and cores for structural sandwiches. Such characteristics as closed cell content, fire resistance, strengths, thermal conductivity and effects of moisture are of importance.

Examples

In March of 1957 Mare Island Naval Shipyard installed the first polyurethane foam as thermal insulation in a refrigerator space. This installation (Figure 17) on the USS *Grayback* (SSG 574) has been highly successful. The foam was directly substituted for the fiberglass originally intended. The refrigerator space was completely fabricated in the usual manner but without the fiberglass insulation.

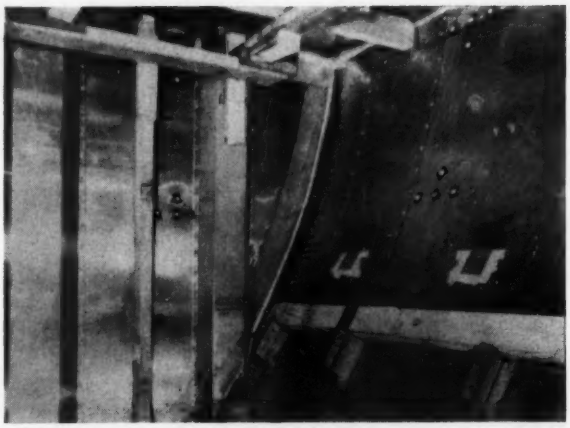


Figure 17. Freeze Room.

Openings 1½" in diameter were cut in the platform deck and in the curved surfaces of the CRES sheathing inside the refrigerator space. Through these openings the liquid urethane foam was introduced by a machine provided and operated by a commercial concern. The liquid flowed to the lowest point in the individual cavities from which it expanded to completely fill the space. When the fill was completed the openings were closed by CRES discs held in place by an adhesive. Such openings can be welded closed. The heat developed melts the foam adjacent to the weld similar in extent to the damage done to a painted steel surface.

In July 1958 the Electric Boat Division installed a similar urethane plastic foam in USS *Skipjack* (SSN 585). In this installation the foam was poured in batches by hand through funnels into the cavities. The separators used to position and fasten the sheathing were of prefoamed plastic strips. Certain vinyl chloride plastic tubes and strips were employed to provide complete isolation of the inside of the space from the exterior.

The urethane foam used in these installations weighed from 2 to 3 pounds per square foot in the *Grayback* and from 5 to 6 in the *Skipjack*. The thermal conductivity of the foam plastic material is little lower than the fiberglass. The coefficient of heat conductivity, K, of the foam is 0.21 compared to the fiberglass and cork at 0.22. The foam adheres to the surfaces against which it foams thus providing a complete insulation through the refrigerator wall and providing continuous structural support to the sheathing. The foam will not shake down and will not take on water since there is no way for wa-

ter to enter. Breather spaces are not needed. All minor cracks, holes, or openings in the cavity are shut by the foam as it rises and seeks to escape.

These experimental installations cost nearly the same as the conventional ones of glass and cork. They are expected to result in better insulation efficiency and much lower maintenance cost.

The urethane materials used in these installations are quite new. Much is yet to be learned about their efficient manufacture and use. New raw materials and foaming techniques have resulted in substantially lower prices and better insulating efficiencies within the past few months. These developments insure that urethane plastic foam will find extensive use as refrigerator space insulation in future ships.

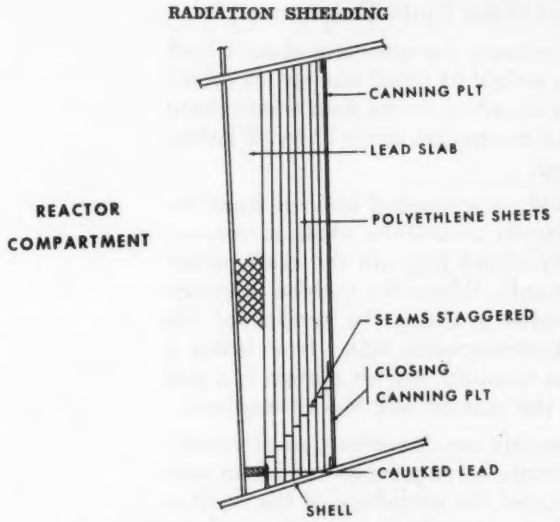


Figure 18. Innerbottom Installation.

Large quantities of another thermoplastic, polyethylene, are being used as a neutron barrier material in the shielding system for nuclear power plants. Here the polyethylene is used because of its high hydrogen content per unit of weight and cost. Each nuclear submarine requires over 50,000 pounds of polyethylene installed as boards to form a thick shielding barrier around the reactor. (Figure 18.)

MISCELLANEOUS ITEMS

Over the past several years, many proposals have been made to produce shipboard items of reinforced plastics which are now made of sheet steel or aluminum. In some instances trial installations have been made. Among other items are chairs, berth pans, joiner doors, wash basins, urinals, tables and benches. (Figure 19)

One of the most often quoted disadvantages for such items in plastics is the potential hazards in shipboard fires. Since these materials will burn they are generally considered inferior to aluminum and steel items. Even though this factor were eliminated, there are other considerations such as the lack of commercial and shipyard experience and unfamiliarity with plastics and with their fabrication which have delayed the acceptance of plastic items. It was easy to convert to aluminum from steel because the processes for working the two materials are similar. Plastics require new design concepts, vastly different fabricating procedures, and in many cases are economically attractive only when a relative large number of identical items are produced.

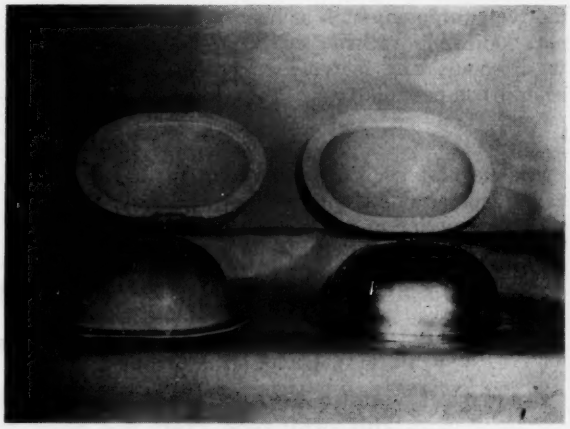


Figure 19. Plastic Basins.

In certain cases, however, both weight and cost savings as well as adequate performance has been shown for plastic items compared to aluminum. An example was a berth pan developed by Mare Island. The Shipyard developed a berth pan design, built tools and produced a number of apparently satisfactory units.

The following are estimates of weights and cost by Mare Island:

	Weight (#s)	Cost
Plastic	21½	$ 55
Aluminum	29½	$122

Subsequent estimates from Norfolk Naval Shipyard did not agree with the Mare Island estimates. The Norfolk figures did not indicate a worthwhile advantage to plastic units.

Recent developments in plastic materials and processing have resulted in a number of successful volume items similar to those mentioned above. For instance, plastic chairs are produced by the tens of thousands per year. They are being sold in competition with those made of other materials. Drawers for furniture, bins and trays and a variety of containers of plastic are finding widespread use. Complex assemblies of sheet metal are being replaced by monolithic moldings of plastics in certain auto-

motive equipment such as heater housings and sport car bodies, in railway coaches such as seats and wash rooms, and in trucks such as fenders, refrigerated compartments and cabs.

SUMMARY

Plastic materials are beginning to find a significant place among the engineering materials used in the construction of naval vessels. They have demonstrated economic and service advantages in a variety of uses. Dielectric, foamed, reinforced, cast, and coating materials derived from the magic of polymer chemistry offer a potential for improvement that we cannot ignore. Marine applications will expand as more is learned of the performance of plastics and of the methods of design, fabrication, inspection, installation, and repair of equipment and components made from these new materials.

CUSHIONCRAFT

The latest manifestation in the development of supra-surface craft which hover above water or land is that Britten-Norman, Ltd., of Bembridge Airport, Isle of Wight, have successfully tested their Cushioncraft. This prototype craft has been constructed to study its potential as a cargo-carrier for the banana plantations in the South Cameroons.

A circular construction of 18 feet, 10 inches in diameter and about 8 feet in height, the Cushioncraft has an empty weight of about one ton. A driver and two passengers are carried in a cab mounted on the deck where there is also cargo space. The craft is designed to operate some 12 to 15 inches above the surface of the water or ground.

The basic principle of operation is that air is ejected inwards from the undersurface through a nozzle, which extends around the whole perimeter. A region of high pressure air is thus generated beneath the craft, which in turn deflects the curtain of air outwards. When the cushion is established, the air curtain is of circular profile touching the surface of the water or ground before wasting to the atmosphere. Apart from being a source of air to replenish the cushion as required, the air curtain is a seal that provides a pressure step between the cushion and the atmosphere.

The basic components of the Cushioncraft are, therefore, an air intake, a compressor driven by an engine, a nozzle arrangement—which in simple form is a single nozzle extending around the periphery of the craft—and an area of structure within the air curtain which takes the uniform cushion load.

In this prototype craft the power unit is a 4-cylinder, twin-overhead-camshaft car engine developing up to 170 B.H.P. This drives a large compressor which runs round the circumference of the craft, and also twin rear-mounted variable-pitch propellers which provide the horizontal propulsion.

In some other designs of air cushion craft, a jet or jets are supplied by air ducted outwards from a centrally mounted fan or compressor. The Cushioncraft's rotor, by running round the periphery, reduces losses by keeping the length of ducting to a minimum.

The compressor, which is driven mechanically by a friction wheel at the rear of the craft, consists of 40 aerofoil blades fixed radially to an inner and outer shroud ring, the whole being kept in place by a series of rollers. The compressor is mounted in a short vertical duct. Below the rotor this duct curves inward so that the air is directed towards the centre of the craft. The duct is 10 inches wide at the efflux, the resultant "thick" jet helping to stabilise the craft when riding on the air cushion.

—from THE SHIPBUILDER AND MARINE ENGINE BUILDER
August, 1960

J. H. POTTER

EARLY FRENCH CONTRIBUTIONS TO THE THEORY OF SPECIFIC HEATS

THE AUTHOR

was educated at Columbia and Johns Hopkins Universities. In addition to five years in the chemical and shipbuilding fields, he has completed twenty years of teaching and research at the university level. He has held academic assignments at Johns Hopkins, the University of Illinois, and at the Stevens Institute of Technology. Since 1955 he has served as Dean of Graduate Studies at the latter institution. During 1959 he was a member of the special Curriculum Review Board at the U.S. Naval Academy. He is a Civil member of the Society.

INTRODUCTION

AT THE DAWN of the nineteenth century the dynamic theory of heat was only partly accepted. Experiments involving thermometry, and the thermal properties of solids and gases brought to light many new laws, some of them independent of the nature of heat itself. The outstanding example was the deduction by Carnot [1] of the Second Law of thermodynamics, which Callendar [2] demonstrated to be valid under either of the theories of heat current at that time.

In Britain, Joseph Black had worked with the idea of specific heats and had formulated a concept of latent heat [3]. However, a very great contribution was made by a group of French scientists and mathematicians, and it is to a sampling of this contribution that this paper is addressed. The measurement, application, and manipulation of specific heats received great impetus at the hands of a few outstanding workers; they paved the way to understanding for all who followed.

MEASUREMENT OF C_p FOR A GAS

Partington [4] considers that the first measurements on the constant pressure specific heat of a gas were made by Lavoisier and Laplace. [5] Their method involved the measurement of inlet and outlet temperatures of a gas flowing through a spiral coil of tubing embedded in ice, and a determination of the quantity of ice melted.

Gay-Lussac [11], using a method proposed originally by Crawford, attempted to determine the specific heats of gases by heating samples in glass vessels then immersing the flasks in water. From the temperature rise of the water the heat capacity of the system was computed. Corrections were applied for the effects of the glass walls. These particular results of Gay-Lussac were of historical interest only, for he inferred erroneously that C_p was a function of pressure even though the experiments were run at low pressures.

A second of his conclusions (I)* was that heat

* Roman numerals refer to quotations in the Appendix.

ANT.^E LAURENT LAVOISIER
(Chimiste),
Membre de l'Académie royale des Sciences.
Né à Paris le 26 Aout 1743.
Mort à Paris le 8 Avril 1794 !!!.

capacities increased as the specific gravities decreased. This suggests that he had stumbled on the high specific heats of hydrogen (which he included in his study) and thought that an underlying general law related the specific heat and the specific gravity. This second conclusion was also in error; his stimulation of the work of others was his principal contribution in this area.

Somewhat later, Delaroche and Bérand [6] undertook some extensive experiments on gases. Difficulties in instrumentation led to poor results. For example, the values of C_p for air and oxygen listed as being greater than water vapor by 19.5 percent and 57.6 percent respectively. However this work had important consequences, as will be shown presently.

Regnault [7, 8] was one of the greatest workers in the field of calorimetry. Some of his measurements of the specific heats of gases are remarkably close to those in use today. He painstakingly refined the instruments and apparatus available in his day. For water vapor he reported C_p=0.475, surprisingly close to the modern value, and as he said —"barely half that found by Delaroche and Bérard."

THE DIFFERENCE BETWEEN THE SPECIFIC HEATS

The difference between the specific heat at constant pressure and the specific heat at constant volume, (C_p-C_v) was investigated by Carnot. [1] In his magnificent memoir of 1824 he gave the world, in addition to the Second Law of thermodynamics and the concept of the reversible cycle, the first statement on the constancy of the difference between the two specific heats.

It must be remembered that no one had measured the specific heat at constant volume at that time. In fact the accurate measurement of C_v was not done until the experiments of Joly [9, 10] (1886-1891). The earlier investigators had worked only on values of the specific heat at constant pressure, and although values of C_p/C_v had been found Carnot worked from a different approach which was more basic.

His method involved two premises: first, the statement of Poisson that for a sudden compression of a gas the volume decreased by $(1/116)$ for each 1°C temperature rise; second, the Gay-Lussac rule that in the neighborhood of °0 C, direct heating of a gas under constant pressure caused a volume increase of $(1/267)$ for each degree rise in temperature. He perceived that whether the gas was heated one degree by compression, or by direct heating at constant volume, the same intrinsic energy was involved. He was therefore able to write the specific heat ratio as:

$$dQ_p/dQ_v=C_pdT/C_vdT=C_p/C_v=(1/116+1/267)/(1/116) \quad \ldots\ldots (1)$$

If C_p is arbitrarily taken as unity:

$$C_v=267/(267+116)=0.698$$

Carnot rounded this off to 0.700, and thus:

$$(C_p-C_v)=1-0.700=0.300$$

This was the first published value for the gas constant, R, in the familiar equation:

$$(C_p-C_v)=R \quad \ldots\ldots (2)$$

To reconcile the steps in his method with modern thermodynamic thinking, the "sudden compression" of the gas must be interpreted as a reversible adiabatic compression. Also the Gay-Lussac value of the ice point at 267° C absolute, was somewhat below the present accepted figure. Be that as it may, Carnot deduced a fundamental relationship within the limits of pressure and temperature existing at that time, in spite of the inadequacy of the basic data. His statement (II) is a model of simplicity and clarity:

> "The difference between specific heat under constant pressure and specific heat un-

J^rh L^s GAY-LUSSAC
(Physicien et Chimiste),
Membre de l'Académie royale des Sciences,
de la société royale de Londres &a.
Né à St Léonard (Dép^t de la Haute Vienne) le 6 Décembre 1778

der constant volume is the same for all gases."

Using the C_p values of Delaroche and Berard [6] Carnot published the specific heat values shown in Table I, taking C_p for air arbitrarity as unity:

TABLE I

Gas	C_p	C_v
Air	1.000	0.700
Hydrogen	0.903	0.603
Carbon dioxide	1.258	0.958
Oxygen	0.976	0.676
Nitrogen	1.000	0.700

The presently accepted value of R=1.985 is the difference between the molal specific heats near room conditions. Carnot's value of 0.700 for C_v/C_p closely approximates modern values as shown in the third column of Table II. In the extreme right hand column the present day ratios of C_p/C_p air are shown. These when compared to the first column in Table I, indicate how crude the Delaroche and Berard measurements must have been.

TABLE II

Gas	C_p	C_v	C_v/C_p	C_p/C_p air
Air	0.241	0.172	0.714	1.000
Hydrogen	3.42	2.44	0.714	14.2
CO_2	0.205	0.160	0.782	0.850
Oxygen	0.217	0.155	0.716	0.901
Nitrogen	0.247	0.176	0.713	1.025

THE RATIO OF THE SPECIFIC HEATS

At the time under consideration many physicists and mathematicians were interested in the measurement of the velocity of sound. Since the days of Newton efforts had been made to reconcile his isothermal equation with the measured values of the velocity of sound. Laplace [12, 13] is credited with the discovery that during the propagation of a sudden compression wave time is too short to permit isothermal conditions. As a consequence, the process is adiabatic, and the equation must be modified by introducing the ratio of specific heats under the radical: (III)

Institut Royal de France
Acad.^e des sciences (Physique générale)
DULONG,
(Pierre-Louis)
Membre de la Légion d'honneur.
Né à Rouen, le 12 Février 1785; † en 1838.

$$\text{Sonic velocity} = \sqrt{C_p\,(\text{pressure})\,/\,C_v\,(\text{density})}$$
$$= \sqrt{kP/\rho} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

An attempt at the direct measurement of the ratio of specific heats was made in the classic experiment of Clement and Desormes. [14] Using a 28 liter vessel with a stopcock and manometer, and with air as the gas to be tested, the vessel was partially exhausted and the pressure, p, was noted at the time the air had returned to room temperature. The valve was then opened briefly and quickly closed. Air from the room entered the vessel and compressed that already inside. When the temperature equilibrium was again reached the pressure p′ was read. During the first step there was an isothermal pressure change:

$$pv = p'v'$$

The second step is adiabatic:

$pv^k = Pv^k$ where P=atmospheric pressure.

Combining equations:

$$k = (\log p - \log P)\,/\,(\log p - \log p') \quad \ldots\ldots \quad (4)$$

Clement and Desormes found k=1.351 for air. While this is lower than currently accepted values, there was undoubtedly moisture present and this would have reduced the value of k.

SADI CARNOT
AT THE AGE OF 17.

Poisson [15] is generally credited with first observing that pv^k=constant, although both Laplace and the workers cited above made use of the ratio of specific heats as an exponent.

Dulong [16] made some interesting studies on specific heats, reporting specific heat ratios of:

TABLE III

Gas	k
Air	1.421
Oxygen	1.415
	1.417
	1.413
Hydrogen	1.409
	1.405

As he worked with the diatomic gases it is not surprising to find that he expected an equal temperature rise in all gases for a sudden compression, however his statement on the dependence of the specific heat at constant volume is not valid. (IV)

CONCLUSIONS

It is not possible to do justice to all of the early French workers on specific heats, even to those mentioned above, in so brief a paper. However, the undergraduate student working at his elementary textbook on thermodynamics might find his labors more interesting if he had some appreciation of the hard work and the false starts that fell to the lot of those who paved the way. Teaching is always aided when a subject is presented in an historical framework and much more could be done to this end.

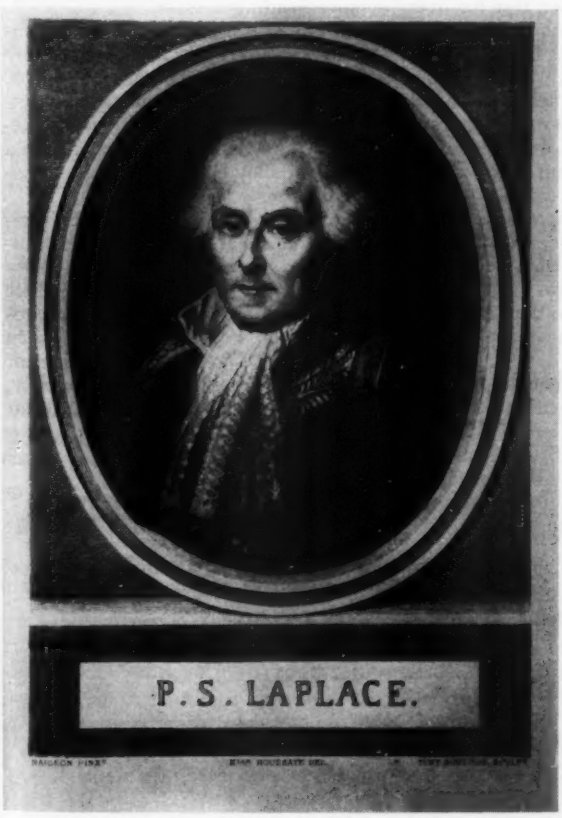
ACKNOWLEDGEMENTS

The author wishes to thank Mr. Bern Dibner for his encouragement and especially for the photographs of the scientists.

APPENDIX

(I) "Les capacités des gaz pour la calorique, sous des volumes égaux, sont d'autant plus grandes, que leurs pesanteurs spécifique sont plus petites."

(II) "La différence entre la chaleur spécifique sous pression constante et la chaleur spécifique sous volume constant est la même pour tous les gaz."



Henri-Victor Regnault.

(III) "La vitesse réelle du son est égale au produit de la vitesse que donne la formule newtonienne, par la racine carrée du rapport de la chaleur spécifique de l'air soumis à la pression constante de l'atmosphere et à diverses températures, a sa chaleur spécifique lorsque son volume reste constant."

(IV) "I° que des volumes égaux de tour les fluides élastiques pris à une même température et sous une même pression, étant comprimés ou dilatés subitement d'une même fraction de leur volume, dégagent ou absorbent la même QUANTITE ABSOLUE DE CHALEUR; 2° que les variations de TEMPERATURE, qui resultent sont en raison inverse de leur chaleur spécifique a VOLUME CONSTANT."

BIBLIOGRAPHY

1. "Réflexions sur la Puissance Motrice du Fetu et sur les Machines propre a développer cette Puissance." S. Carnot, Chez Bachelier, Libraire, Paris, 1824.
2. "The Caloric Theory of Heat and Carnot's Principle." H. L. Callendar, Proc. Physical Society of London, v.23, pp 153-189, 1911.

3. "The Discovery of Specific and Latent Heats." McKie, Heathcote and Andrade, Edw. Arnold & Co., London, 1935.
4. "The Specific Heats of Gases," J. R. Partington & W. G. Shilling, Ernest Benn Ltd., London, 1924.
5. Memoires de Physique et Chimie, v.i, part 1, 3rd. memmoire, pg. 134 et seq., 1805.
6. "Sur la Détermination de la Chaleur Spécifique des Differens Gaz." Delaroche & Bérard, Annales de Chimie, v.85, pg. 72 & 224, 1813.
7. "Researches upon the Specific Heat of Elastic Fluids." M. V. Regnault, Phil. Mag., V. 1853, pg. 473.
8. Memoires de l'Academie des Sciences. M. V. Regnault, v.21 & v.26.
9. "On the Specific Heats of Gases at Constant Volume." J. Joly, Proc. Roy. Soc. Ser. A., v. 48, pg. 440, 1890.
10. "On the Method of Condensation in Calorimetry." J. Joly, Proc. Roy. Soc. Ser. A., v. 41, pp. 352-371, 1886.
11. "Pour déterminer les variations de température qu'eprouvent les gaz en changeant de densité, et considérations sur leur capacité pour le calorique." L. J. Gay-Lussac, Mem. de la Soc. d'Arcueil, v. 1, pp. 180-203, 1807.
12. "Sur la Vitesse du Son dans L'Air et dans l'Eau." P. S. Laplace, Annales de Chimie et de Physique, v. III, pp. 238-241, 1816.
13. "Note sur la Vitesse du Son." P. S. Laplace, Annales de Chimie et de Physique, v. 20, pp. 266-269, 1822.
14. Observations sur la Physique. v. 89, pg. 321, 1819.
15. "Sur la Chaleur des Gaz et des Vapeurs." M. Poisson, Annales de Chimie et de Physique, v. 23, pp. 337-352, 1823.
16. "Recherches sur la Chaleur Spécifique des Fluides Élastiques." M. Dulong, Annales de Chimie et de Physique, v. XLI, pp. 113-159, 1829.

TUBES FOR CARGO HEATING COILS IN OIL TANKERS

For many years steel pipe, 2″ SPS (2.375″ OD x 0.154″ wall) or heavier, has been used in grids for steam heating crude oil cargos in tankers. Heat is applied while the tanker is under way to keep the oil fluid so it can be speedily pumped into receiving lines when the ship reaches port.

Crude oil is corrosive to steel at the temperatures reached at the surface of the pipe, especially when salt solution is present. Further rusting and pitting occur when the compartment is ballasted with sea water or when it is cleaned with hot sea water at high velocities. As a result, steel pipe heating coils may begin to fail within two years, and complete replacement must often be made within five years.

Certain copper alloys are highly resistant to corrosion under these conditions and have the further advantage of being galvanically cathodic to the steel walls of the compartment. The area of the coils is small compared to the area of the compartment walls, so no significant galvanic corrosion of the steel structure takes place.

Anaconda Arsenical Admiralty-439 tube coils have been on test for over two years in a cargo compartment of National Bulk Carriers' 45,000-ton tanker, S.S. Phoenix, operating between the Near East and the United States. Inspection shows no significant corrosion. This alloy is believed to be the most economical one for oil tanker heating coils.

Aluminum brass heating coils have been in use successfully for several years, and for the tubes in such coils Anaconda Ambraloy-927 can be furnished, but it is higher in price than Arsenical Admiralty-439, which has adequate corrosion resistance.

Tube sizes equivalent to nominal 1¼″, 1½″ and 2″ Type K water tube (1.375″ OD x 0.065″ wall, 1.625″ x .072″, and 2.125″ x .083″, respectively) would be considered for the makeup of a heating system. The tubes are thus considerably lighter in weight than steel pipe.

Tubes are furnished soft so that they may be bent by the use of suitable bending equipment. Bends should be relief annealed at about 800°F to remove bending stresses.

The use of flanged fittings for assembling heating grids has been largely supplanted by expanding the end of one tube to fit over another and brazing the joint. Where fittings are required, cast red brass fittings, attached by silver alloy brazing, are quite satisfactory.

Technical Service: Anaconda metallurgical engineers are available for consultation on the use of tubes in oil cargo heating and to aid in selecting the best tube alloys for your heat exchanger requirements. For such assistance, see your Anaconda representative or write: Anaconda American Brass Company, Waterbury 20, Conn. In Canada: Anaconda American Brass Ltd., New Toronto, Ont. 5960B

ANACONDA®

TUBES AND PLATES FOR CONDENSERS AND HEAT EXCHANGERS

Anaconda American Brass Company

MAGNETOHYDRODYNAMIC GENERATORS

ACKNOWLEDGMENT

This article, reprinted from the July, 1960 issue of "Westinghouse Engineer" was written by Mr. Stewart Way, Research Laboratories, Westinghouse Electric Corporation.

ABOUT 130 YEARS ago, Michael Faraday discovered that a conductor moving in a magnetic field could be made to generate an electric current. This principle has traditionally been applied to produce electric power by mechanically rotating solid copper bars past energized field windings. However, Faraday's experiments also showed that power can be generated by substituting a flowing liquid metal, such as mercury or some other conducting liquid, for the copper bars. A device that uses a fluid conductor to produce an electric current is a magnetohydrodynamic generator.

THE MHD GENERATOR

The word *magnetohydrodynamics,* abbreviated MHD, stands for the branch of physics that encompasses both electromagnetic and fluid-dynamic phenomena. Practical realization of MHD power generation appears at the present time to depend on the use of a conducting gas. For the gas to be conducting, a certain number of free electrons must be present, along with an equal number of ions, plus the main body of un-ionized gas. The most direct approach to partially ionize gas, and thereby make it conducting, is to heat it sufficiently. However, the temperatures required for sufficient gas ionization in this case are beyond the limits of use of all known materials.

However, when a gas is "seeded" with an alkali metal, such as potassium or cesium, adequate electrical conductivity can be realized at somewhat lower temperatures—in the range of 4000 to 5000°F. The possibility of MHD generation, as currently conceived, hinges on the small region of overlap between the temperatures that a few materials are able to tolerate, and the temperatures that are necessary, even with seeding, to obtain adequate electrical conductivity.

In an MHD generator, hot ionized gas travels through a magnetic field, which is applied at right angles to the flow, and past electrodes that are in contact with the stream of gas (Figure 1b). Electrons in the gas are deflected by the field and, between collisions with other particles in the gas, they make their way diagonally to one of the electrodes. An electric current is produced as the electrons move from the anode, through the load, to the cathode, and back again to the gas stream.

The voltage at the terminals of an MHD generator is directly proportional to the intensity of the magnetic field, the gas velocity, and the distance between electrodes. A generator will supply maximum power when the load connected to its terminals has a voltage drop equal to one-half of the open circuit voltage.

Near peak power, the efficiency of a magnetohydrodynamic generator may be as low as 50 per cent, because of the I^2R losses. But efficiencies in the 80 to 90-per cent range are possible when the generator is operated somewhat below maximum

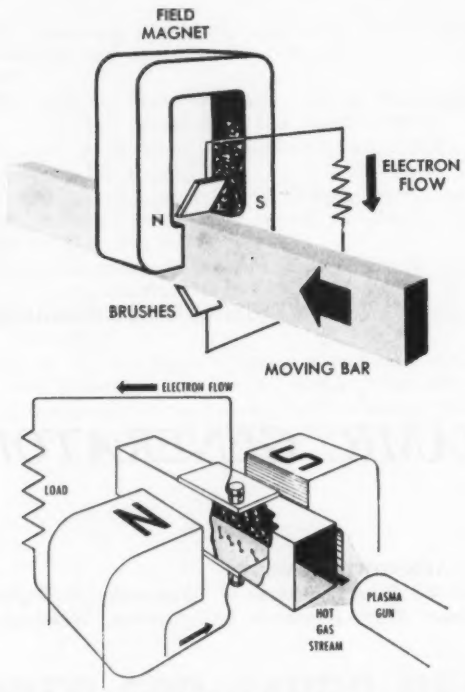


Figure 1(a). This sketch illustrates Faraday's original concept, which formed the basis for the unipolar (or homopolar) generator; (b) The MHD generator employs the same principles, with a conducting gas replacing the moving bar.

power. This corresponds to the efficiency of a conventional steam turbine-generator combination, which is about 80 per cent.

The overall thermal efficiency of a plant using an MHD generator might be as much as 60 per cent, compared with 40 to 42 per cent for the most modern conventional power plants. The high efficiency of the MHD plant arises principally from the high temperature that is used; this high temperature is required for gas ionization.

MHD GENERATOR CYCLES

Power systems using MHD generators fall into two categories: *open* systems where the working gas consists of products of combustion, and *closed* systems in which an inert gas, such as argon or helium, is continuously recycled. The complete system in either arrangement require a compressor to overcome the pressure drop normally occurring in the MHD generator, and a regenerator and waste heat boiler to recoup maximum energy from the hot gas stream.

One possible arrangement for a closed-cycle MHD plant is shown in Figure 2. The gas consists of helium, seeded with two-per cent cesium. The plant shown would generate 380 megawatts. Since the MHD generator develops direct current, a converter is required to produce an ac output.

The capital cost of the converter would be appreciable, although not prohibitive. Scientists are also studying the possibilities of direct MHD generation of ac power. Several approaches to this problem appear promising.

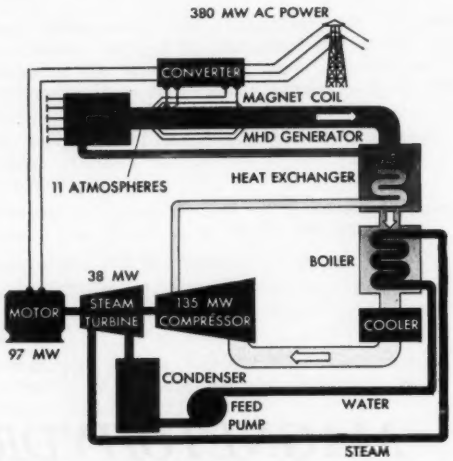


Figure 2. A proposed 380-mw central station plant using an MHD generator as the power source.

The MHD generator for the system shown in Figure 2 would be 50 to 60 feet long, and would operate at about 4000°F. A reactor may be used as the heating device. However, the development problems of this reactor, or of the heat exchanger that preheats the gas stream should not be underestimated.

A boiler is used to recover heat from the gas stream and generate steam. This steam drives a 38-megawatt turbine, which powers the gas compressor. The steam turbine is assisted by a motor, which consumes some of the MHD generator output.

To circumvent reactor development problems, two other possibilities are being considered: (1) a combustion-fired external heater could be used in the closed loop helium system of Figure 2; or (2) an open system could be used in which the combustion gases pass directly through the MHD generator. The latter arrangement is shown in Figure 3. In this case, a surplus of power can be generated in the steam loop so that an electric generator is present, replacing the dc motor used in the closed system. Operating temperatures in the MHD generator in the open system must be higher, however, because electron mobility is lower in combustion-product gases than in helium. Another difference is that potassium rather than cesium is used for seeding because cesium is too costly to discharge. In either case, means would have to be taken to avoid air pollution by the hydroxides of the seeding elements.

RESEARCH IN MHD

Problems ahead in MHD generation development are in the general areas of physics, materials, and

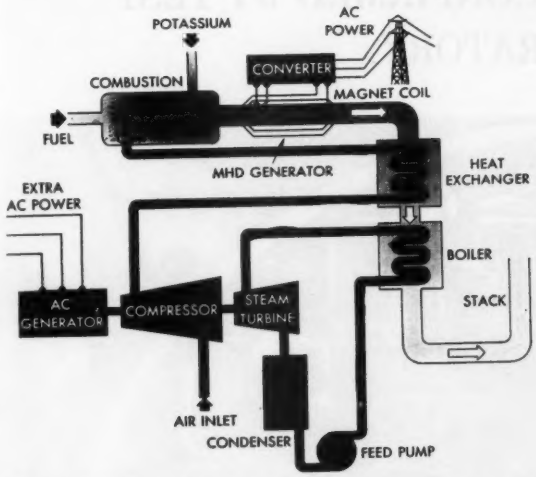


Figure 3. Magneto-hydrodynamic open system using fossil fuels. Combustion products replace helium-cesium mixtures in conventional units.

engineering technology. Further work needs to be done in laboratories to obtain more reliable data on conduction of electricity in gases, and to provide a better understanding of the basic mechanisms of energy and momentum exchange in the MHD generator.

Materials must be developed to better withstand high temperatures, sudden temperature changes, and chemical interaction with the alkali-metal seeding materials. New engineering and design approaches must be found to build durable parts of ceramic, which have conventionally been made of metal. Durable electrodes must be developed to withstand high temperatures and chemical attack, and yet they must be good conductors.

To study these problems, several lines of research are being pursued. First is a basic study of materials and their properties, and investigations in gaseous electronics. Secondly, two experimental MHD generators have been built and are in operation. One of these is relatively small, for laboratory-type studies; it burns hydrogen and oxygen, seeded with potassium.

The second, generator project is a larger machine, which has generated about nine kilowatts. About twice this figure is expected ultimately. The machine has been run for four minutes continuously. This generator burns diesel oil and oxygen, with potassium soap dissolved in the oil as a seeding element. Oxygen, rather than air, is used merely as a convenience to avoid the need for a large air preheater. Flow rates are 0.8 lb/sec of oxygen and 0.3 lb/sec of oil-soap mixture.

The generator field, 14,000 gauss, is produced by an electromagnet, which is mounted on a platform that can be raised or lowered.

Although MHD devices for producing short bursts of power have already been demonstrated and may offer potential in specialized applications, such as in satellite communications systems, a generator must operate continuously for the practical generation of commercial electric power. The machine referred to previously which burns diesel oil and oxygen, is the only MHD generator that has been able to produce kilowatts of power over a sustained period of time. Further, this generator operates on combustion products rather than on a gas heated by an electric arc. In short, it demonstrates generation of electric power directly from a hot gas stream produced by a combustion process.

The generator section proper has a flow cross section of 1⅝ by 4⅞ inches, and is 16 inches long. Three pairs of graphite electrodes are mounted on opposite sides of the stream, with a distance of 4⅝ inches between their faces. The insulating side walls are of 1¼ inch thick zirconia. Flow of the combustion gas is 1.1 pounds per second at the design point, and the temperature is about 4600°F. The velocity is approximately 1800 miles per hour, at a pressure of about one atmosphere (total temperature is 5000°F). The oil-soap mixture is burned with oxygen in a specially designed swirl-type combustion chamber that discharges into a mixing plenum, and then into the generator proper. Water-cooled side walls are used throughout the generator, and zirconia lining is used everywhere except in the combustor flame tube, which is made of stainless steel.

This model is being used to investigate generator sidewall designs, electrode materials and configurations, power distribution in the generator, chemical reactions with the seeded gas, operating characteristics of the MHD generator, electrode potential drops, and potential and temperature distributions.

THE FUTURE OF MHD

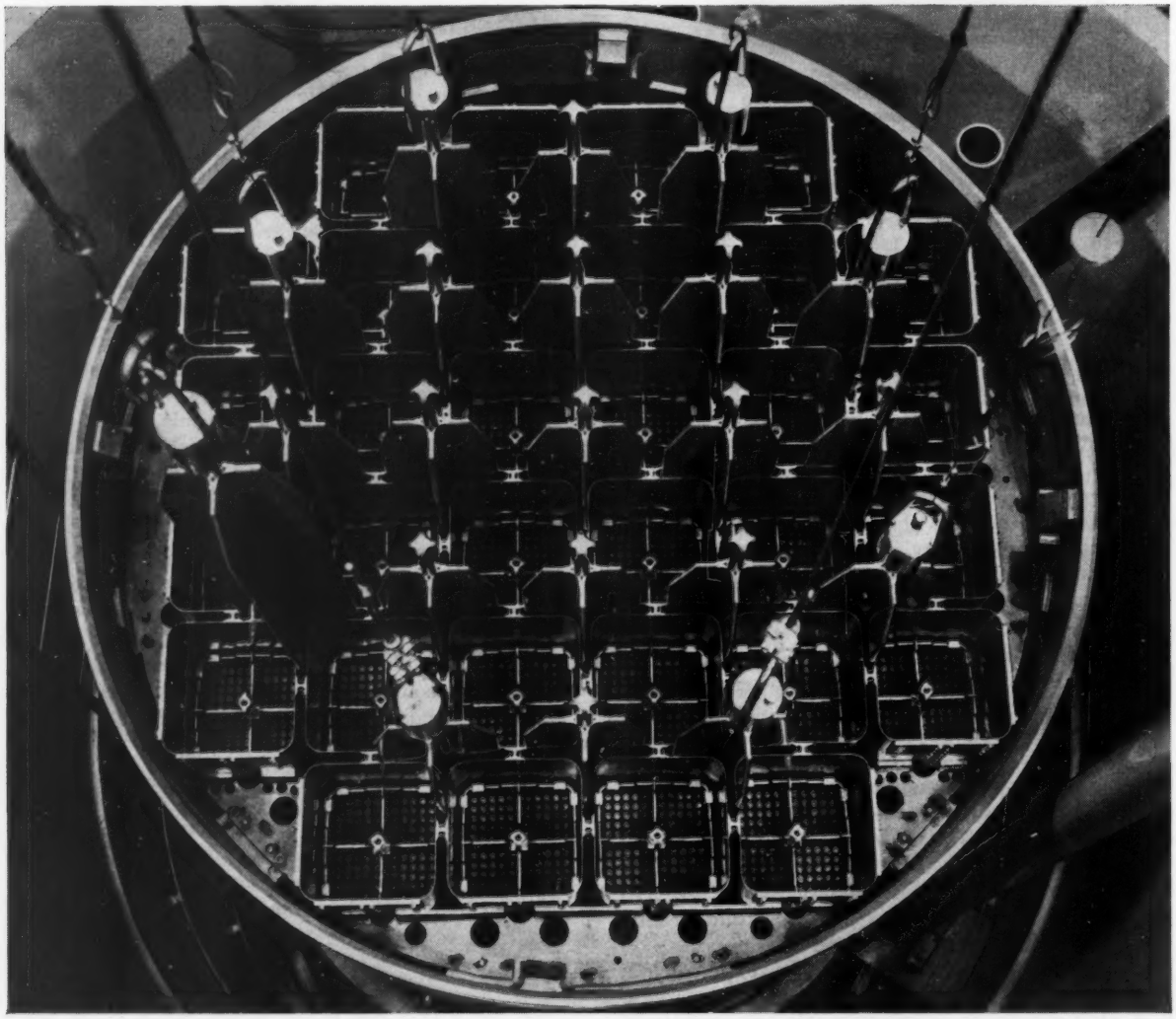
Before a practical power source using MHD generation can be built, much work remains to be done on the problems already mentioned.

For straight-through MHD generators, several configurations are possible, including constant pressure, constant area, and constant velocity designs, or various combinations of these. Other geometries also should and will be investigated. The indirect-fired closed-loop system, adapted to direct ac generation, would seem to be one of the most promising arrangements upon which to concentrate vigorous effort.

Scientists are now actively pursuing the background researches, the material studies, and the development work that will be essential if MHD power is to become a practical reality.

N.S. SAVANNAH PROGRESS REPORT:

CORE DESIGN CALCULATIONS CONFIRMED BY TEST AT CRITICALITY IN B&W LABORATORY



The core for the N. S. SAVANNAH was, for the first time, made critical (at zero power) in an open test tank at B&W's Critical Experiment Laboratory at Lynchburg, Virginia. Except for pressure and temperature, conditions of loading and start-up as nearly as possible duplicated those in the reactor pressure vessel. Design and engineering calculations were confirmed within closer limits than had been predicted. Since radioactivity during and after operation will preclude further close inspection, tests such as these permit flexibility and accuracy impossible in the operating environment. Successful completion of the tests on this core—designed and built by B&W—is another step toward the sailing of the SAVANNAH—and the nuclear future of our merchant marine service. The Babcock & Wilcox Company, 161 East 42nd St., New York 17, New York.

AE-78

B&W

THE BABCOCK & WILCOX COMPANY

NUCLEAR POWER APPLICATIONS

Complete nuclear systems, cores, components, fuel elements, nuclear research and development

"THE MARINE ENGINEER AND NAVAL ARCHITECT"

MACHINERY PROPOSALS FOR A MAMMOTH LINER

ACKNOWLEDGMENT

The following article, reprinted from the April 1960 issue of "The Marine Engineer and Naval Architect," was prepared by the staff of that publication.

One of a number of proposals by the Heavy Plant Division of Associated Electrical Industries Ltd. for a 300,000 shp quintuple-screw liner is here briefly discussed. Turbo-electric machinery, with initial steam conditions of 1,500 psi and 1,000 degrees F, would be put forward for such a vessel. Two dual-line turbo-alternator sets with reheat are favored, and a propulsion-only fuel rate of 0.376 lb per shp-hr is envisaged.

THE QUESTION OF how any future very large passenger vessel would be powered is one of great fascination to every marine engineer. It is over thirty years since the machinery of the *Queens* was initially designed; and since they went into service advances in marine steam engineering in Europe and the United States have been significant—even dramatic. As the number of companies who would require a very large ship of high power and speed must necessarily be limited it is not surprising that few proposals of this kind have actually reached the design stage. The American liner *United States* is the most noteworthy vessel of this type to be completed in recent years but virtually nothing has been published about her machinery. It is popularly claimed that she has what is virtually an installation of U.S. Navy aircraft-carrier machinery of the latest type.

An article in the January issue of *The Marine Engineer and Naval Architect* promoted correspondence on this subject and has led to our being able to describe a firm proposal recently put forward by the Heavy Plant Division of Associated Electrical Industries Ltd., probably better known to our readers as the B.T.H. of former years. This company's experience of turbo-electric drive is, of course, lengthy and impressive. The first large turbo-electric ship which they engined was the *Viceroy of India* of 1928, and since then a number of vessels of different types have been fitted with their turbo-electric machinery. Among these are the *Strathaird* and *Strathnaver* of 1931, the fast New Zealand vessel *Rangatira*, the post-war ships *Hinemoa* and *Maori*, the single-screw tanker *Helicina* and her sisters of about 1946 and, more recently, the four Shell standard 18,000-tonners.

Briefly, the project to be discussed is to install two sets of 150,000 shp cross-compound dual-line

reheat turbo-alternator sets taking steam at 1,500 psi and 1,000 deg F, with reheating at 375 psia and 1,000 deg F. This generating plant would supply power to five 60,000 shp at 250 rpm double-unit synchronous propulsion motors. The dual line sets would each consist of two shafts mechanically independent, but locked in parallel electrically and with a series-parallel steam flow. As far as the generating plant goes, this is simply taking major base-load power station practice to sea. A.E.I. Ltd. are building five such turbo-alternator sets for a public utility in South America and the propulsion motors put forward would actually be of slightly smaller dimensions than those supplied by A.E.I. for the *Canberra* due to the higher propeller speed. The proposal presents no problem from an engineering point of view.

By generating in such large units the electrical transmission losses could be guaranteed at 4 per cent,* which it is claimed is a lower figure than the combined astern turbine windage and reduction gearing losses of a conventional geared turbine installation. The use of unirotational turbines would enable the highest practical steam conditions to be used without the complication and loss of efficiency arising from the need to provide for rapid thermal transients when maneuvering or going astern. The steam temperature chosen, moreover, does not call for the employment of very costly austenitic steels.

The turbo-alternator sets would be running all the time while maneuvering so that power could be applied to the propellers instantly. Full ahead power would always be available astern.

The propulsion motors can be laid out to the best advantage to reduce shafting lengths as they are independent of the position of the generating plant; this is well brought out in the accompanying machinery layout drawing. A further advantage is that more economical running conditions can be obtained at reduced speeds by shutting down one turbo-alternator. Absence of vibration and gearing noise are favorable points for a turbo-electric passenger ship layout, while propeller-induced hull vibration can be kept to the minimum by electrically synchronizing the shafts in any predetermined phase relationship. So much for general considerations and advantages. Let us now examine the proposals a little closer.

TURBO ALTERNATORS

Each set of 150,000 shp propulsion turbines would consist of two lines of rotating machinery as follows:

A-line. An eleven-stage double-casing H.P. turbine, a three-stage section of the I.P. turbine, a six-stage dual-flow double-casing L.P. turbine and a 56,860 kw two-pole air-cooled turbo-type alternator.

B-line. A twelve-stage section of the I.P. turbine, a six-stage dual-flow double-casing L.P. turbine and a 56,860 kW two-pole air-cooled turbo alternator. For each line there is a separate governor and single axial-flow condenser of fabricated construction.

All the turbine rotors would be machined from solid forgings to obtain high critical speeds, short axial length, good factors of safety and freedom from loose wheels, features which aid starting and loading and assist in ensuring wheel stiffness and the avoidance of blade vibration problems. The steam rotors would be solid-coupled throughout and would be located axially by a Michell thrust in the center pedestal bearing.

The steam flow is from the boilers through the emergency stop valves and nozzle group control valves to the H.P. turbine on A-line at 1,500 psi and 1,000 deg F. The steam leaves the H.P. turbine at 390 psi and passes to the reheater where the temperature is restored to 1,000 deg F, returning to the three-stage section of the I.P. turbine, still on the A-line, at 360 psi. On leaving this short I.P. section the steam crosses over to the B-line and enters the eleven-stage I.P. section. After this the steam flow divides, half returning to the six-stage double-flow L.P. turbine on the A-line and half continuing to the B-line double-flow L.P. turbine.

A dual-wall H.P. turbine casing is necessary to cope with changes in boiler pressure and temperature such as might arise during rapid maneuvering. Steam would be admitted in a symmetrical manner to avoid distortion. Separate steam chests would be located at the front or side of the set as convenient.

The entry of reheated steam into a separate I.P. casing, although increasing the length of the set, avoids a complex multi-H.P.-I.P. steam inlet arrangement of the H.P. casing, and also enables the hottest steam zone to be near the center of span. Increased space is also made available for the I.P. steam intercept control and emergency valves and piping. (A reheat set of these dimensions requires additional trip valves before the I.P. turbine as otherwise the volume of steam in the reheater, not being under control of the governor, might still cause the turbine to overspeed after the main T.S.V. had closed.)

The exhaust casing outer shell would be of fabricated construction for strength and lightness. Rotor blading would be of chrome molybdenum alloy steel for the H.P. and earlier I.P. stages and chrome alloy steel for the later ones. The H.P. cylinder would have built-up diaphragms with chrome molybdenum alloy segments and webs of forged 3 per cent chrome molybdenum steel. All the I.P. stages would be of built-up type except the last three, which would be in high-grade cast iron with chrome alloy steel plates cast in position. This construction would be adopted for the L.P. diaphragms.

* This figure allows a good margin for the supply of excitation by a considerably less efficient auxiliary turbine. The transmission losses, excluding excitation, are 3 per cent.

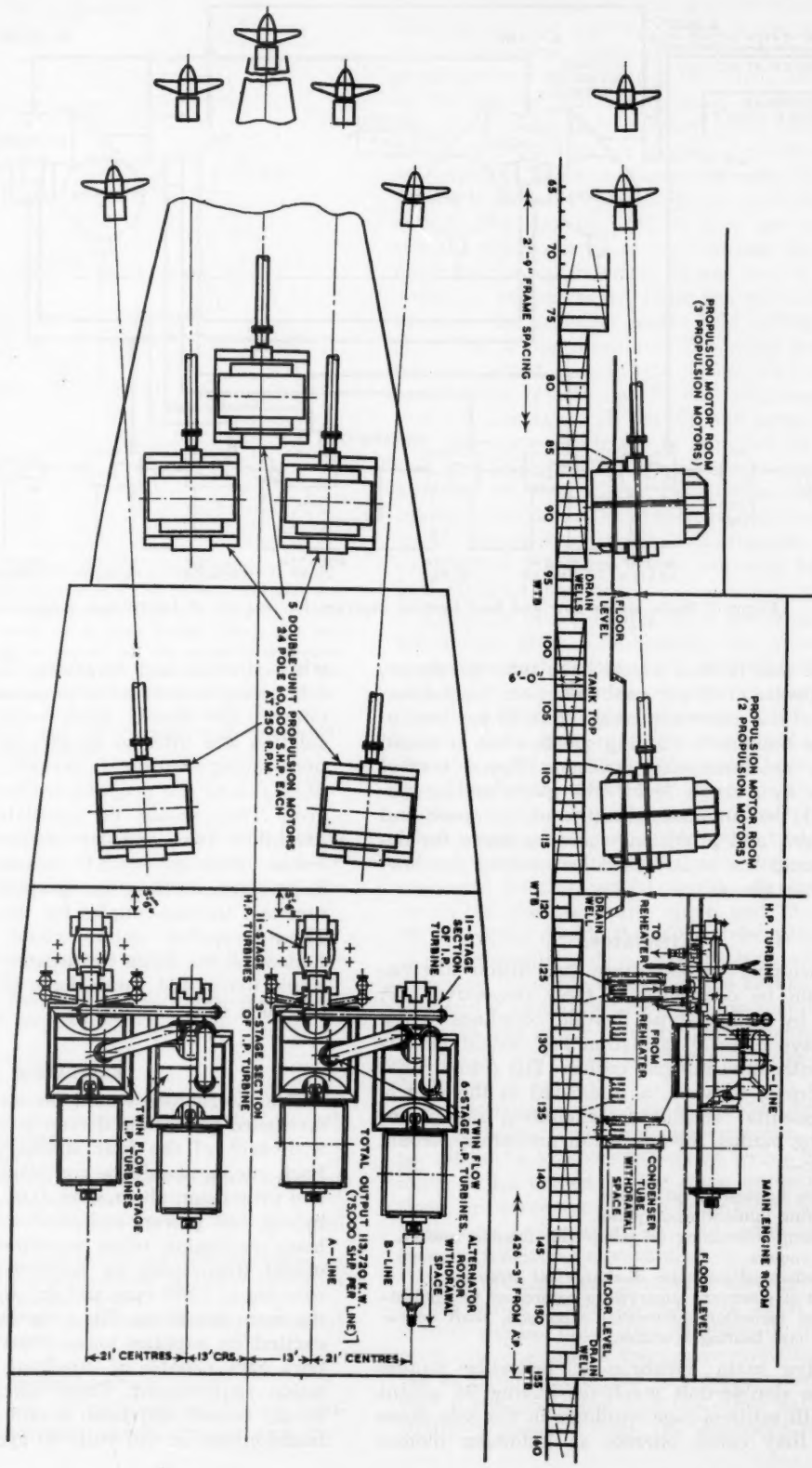


Figure 1. Diagrammatic layout of turbo-alternator and propulsion motor rooms for a proposed trans-Atlantic liner of 300,000 shp distributed over five screws. Proven land power station practice would be freely drawn upon for the turbo-alternators and the synchronous propeller motors would be double-unit machines with independent axial-flow ventilating fans and air coolers. Steam conditions would be: 1,500 psi and 1,000 degrees F. and the steam would be reheated to 1,000 degrees F. after leaving the high-pressure units. An estimated specific fuel consumption (propulsion only) of 0.376 lb per shp per hour is suggested as is a weight figure for the main machinery and its essential auxiliaries of 110 shp per ton.

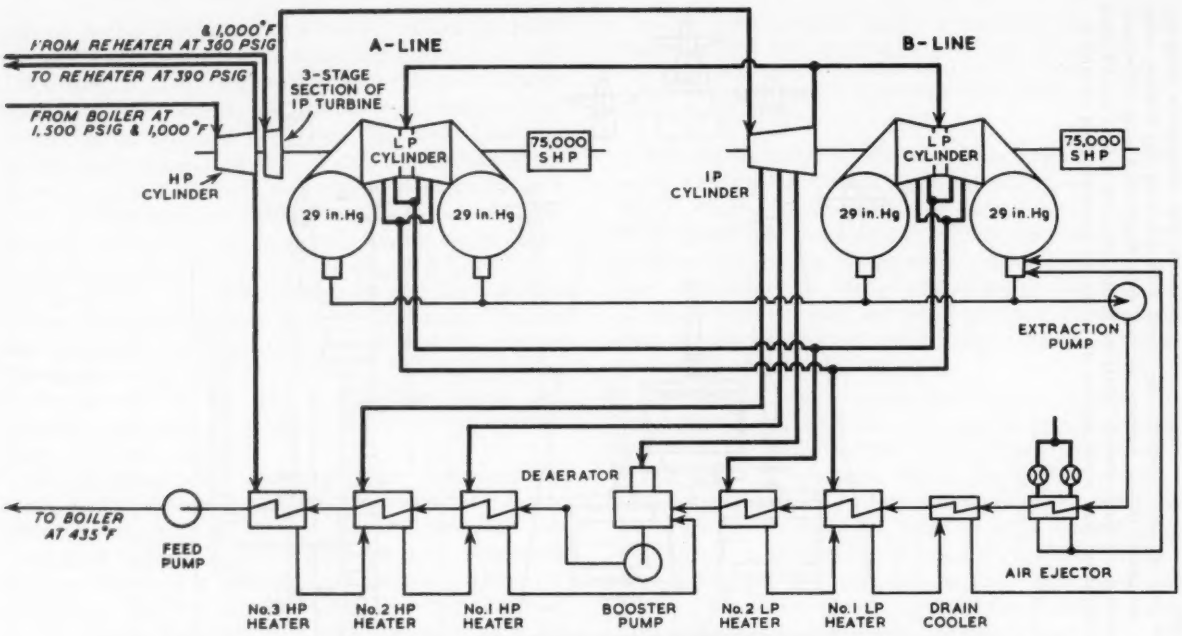


Figure 2. Basic steam flow and feed heating diagram for one set of 150,000 h.p. generating plant.

Both A and B lines would have twin governors, one to operate at 25 per cent full speed for maneuvering and the other adjustable from 85 per cent to above the maximum running speed, when it would act as a pre-emergency governor. Speed control would be by a single lever. The gland sealing system would be automatic throughout the speed and load ranges, and provision would be made for desuperheating the steam used for sealing the low-temperature glands.

ALTERNATORS

The two-pole turbo-pattern propulsion alternators would be connected to their respective L.P. turbines by bellows-type flexible couplings. They would have class B insulation and would be air-cooled, with axial integral coolers. The rotors could be withdrawn forward, as indicated in the sketch.

The essential auxiliaries, excluding salt water circulating pumps, for one set of machinery, would comprise:—

Two main lubricating oil pumps.
One barring lubricating oil pump.
One jacking lubricating oil pump (for floating rotors).
Two oil coolers.
Two mechanical/magnetic discharge oil strainers.
Two sets of electronic supervisory equipment for indicating and recording differential expansion, shaft eccentricity and bearing vibration.

The five main synchronous propeller motors would be double-unit machines having 24 salient poles, with squirrel-cage windings in the pole shoes so that they could operate as induction motors when starting and reversing. They would be self-lubricating and fitted with jacking pumps for running at low speeds. They would have class B insulation and internal heaters to prevent condensation during shut-down periods. This provision applies also to the propulsion alternators and control gear. They would be ventilated by independent axial-flow fans and air coolers mounted on the frame. Fittings would include tacho-generators, Selsyn transmitters for propeller rotation indication and thermo-couples for the supervisory panel. These propeller motors would, it might be mentioned, be too large to dispatch from the works as single items, and would have to be reassembled on the dock side.

EXCITATION

The alternators would be separately excited by air-cooled generators driven in tandem at 1,200 rpm with each of the four auxiliary turbo-alternators. Each exciter would be continuously rated to excite two propulsion alternators (i.e., 100 per cent stand-by) at full power, and short-time rated to deliver boost excitation when maneuvering. The exciters would themselves be energized by pilot exciters running at 1,800 rpm and driven by Vee-belts from the main machines. The propeller motors would be excited by supplies taken from three silicon rectifiers, each capable of supplying half the total excitation requirement. These silicon rectifiers would be air cooled and take incoming supplies through transformers at 440 volts 60 cycles.

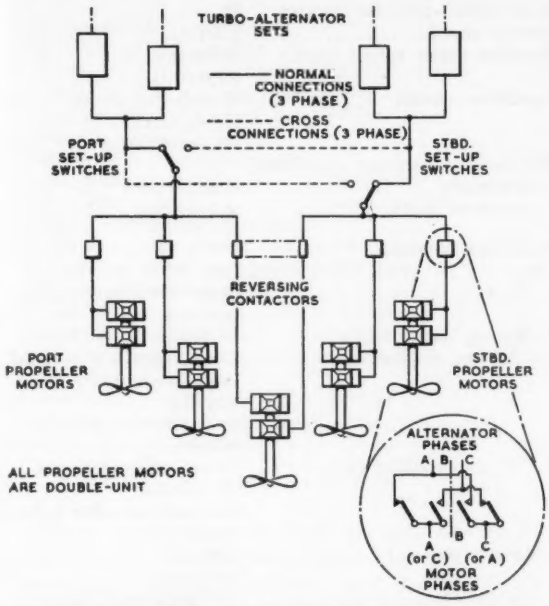


Figure 3. Simplified electrical main circuit diagram showing detail of reversing contactors. The set-up switches are opened to enable the connections between alternator and motor stators to be made on a dead circuit. They also enable one alternator set to supply all the propulsion motors by means of the cross-connections. Reversing is carried out by changing over the connections between any two phases (in the instance shown, A & C). This diagram also shows how the five shafts can be "mechanically-paralleled" through the center shaft motor.

Comprehensive supervisory instrumentation would be supplied for each power plant and for the electric transmission only could embrace the following:—

Speed and direction indicators, giving turbine and propeller revolutions.
Propeller rotation indicators and revolution counters.
a-c voltmeters and phase changeover switch.
a-c ammeters.
d-c excitation voltmeters.
d-c excitation ammeters.
Plug-in type wattmeters for measurement of electrical power supplied by each propulsion turbo-alternator set.
Integrating kwhr meters.
shp indicating meters.
Thermocouple indicators with multi-way switch for stator windings and cooling systems.
Earth alarm bells with cut-out switch, and indicating lamps for alternators.
Alarm bells with cut-out switch and separate indicating lamps for excessive temperature of cooling air from alternators and propeller motors.
Short-circuit relays and excitation tripping devices for the propulsion circuits.

BASIC TURBO-ELECTRIC DRIVE

The simplest form of turbo-electric drive comprises a turbo-alternator and a synchronous propeller motor equipped with a squirrel-cage induction winding for starting. Three levers are provided, for direction, starting and speed. The starting procedure would be to run the turbo alternator at 25 per cent of full speed under governor control and then, using the direction lever, close the appropriate contactors for ahead or astern operation, as required. These contactors connect the alternator stator to the propeller motor stator on a 'dead' circuit. The starting lever is then operated to excite the alternator field only, causing the propeller motor to run up to nearly 25 per cent of full speed ahead or astern, as an induction motor, and then to excite the propeller motor field so that it is synchronized to the alternator. The speed lever is then used to adjust the turbine speed. To reverse, the speed lever is returned to the maneuvering position (25 per cent full speed) and propeller motor and alternator excitation is removed by operating the starting lever. The propeller motor stator is reswitched on 'dead' circuit for opposite rotation with the direction lever. Excitation is then restored and speed adjusted as before. Mechanical interlocks ensure that the three levers can only be operated in the correct sequence.

Applying this principle to a five-shaft proposal introduces little complication, for although each propulsion turbine comprises two separate lines A and B, driving identical alternators, they are electrically locked in synchronism, and are therefore treated as a single unit. Turbine speed is thus under the control of a single speed lever and ship speed under the control of two—one port and one starboard. The center screw would not be powered when maneuvering and the port turbine would power the port outer and inner screws, while the starboard turbine would supply current independently to the starboard outer and inner screws. Maneuvering could, therefore, take place as on a twin-screw ship and, in one proposal, only a single direction lever for operating the reversing contactors and a single starting lever for operating the alternator and motor field contactors for those drives associated with each turbine would be needed on each side.

An alternative would be to provide direction and starting levers for each propeller motor. This would permit the two motors associated with a turbo-alternator to be driven in the same or opposite rotations, or one motor only to be powered as required. This would, however, call for additional watchkeepers when maneuvering.

Once the ship had proceeded clear of harbor the center screw would be powered. Each propulsion motor would have two electrically-independent units and one unit of the center propeller would be fed in parallel with the two port motors from the port turbo-alternator, and the other unit would be similarly powered from the starboard turbo alter-

nator. The speed of all motors would still be controlled by two speed levers.

PROPELLER BLADE PHASING

It would be possible to synchronize the five screws at sea with the blades at a predetermined phase relationship, in order to minimize hull vibration. This can be done if individual starting levers are provided for each propeller motor. Such procedure would be effected as follows: The port and starboard alternators would be run at quarter speed, driving the five motors as induction machines, as in the normal method of starting. Both units of the center propeller motor would be excited so that it ran as a synchronous motor. This operation would synchronize the port and starboard turbo-alternators, each becoming 'mechanically-paralleled' through the motor shafting. The next step is to excite, and thereby synchronize, the motors on the outboard and inboard shafts in turn, *as their associated screws achieve the required blade relationship with the center screw.* The speed of the two turbo-alternator sets is then raised as required. Load sharing between them presents no difficulty. When mechanically paralleled through the motor shafting, the port and starboard drives are completely independent electrically. The correct blade relationships would be adjusted prior to synchronizing by varying the slip of the propeller motors. Precise indication of blade position could easily be arranged on the control panel by means of differential Selsyns.

Considerable part-load economy could be obtained with a turbo-electric plant of this type, as up to 70 per cent of full-load speed could be reached with the motors powered by one turbo-alternator set. By slightly increasing the alternator size only, this maximum of 70 per cent full speed on one turbine could be increased to 80 per cent.

AUXILIARY POWER

So far, the generation of auxiliary power has not been mentioned. A feature of turbo-electric drive which is worth considering is the powering of auxiliaries, particularly those in the engine room that can operate over a frequency range, from the propulsion circuit, resulting in an improved overall fuel consumption. Once the ship is approaching service speed, auxiliary power can be taken from the propulsion circuit through step-down transformers. Alternatively, an auxiliary unit of probably 3,000 kw could be built into the propeller motor to *generate* at the required voltage, without increasing the motor dimensions.

SUMMARY OF PROPELLING MACHINERY

Power, maximum continuous ....300,000 shp at 250 rpm
No. of propellers .....Five
No. of poles—alternators .....Two
No. of poles—propeller motors ...24
Turbine speed .....3,000 rpm
Propeller motor rating (each) ...60,000 shp
6,600 volts
Propulsion circuit .....50 cycles per second
Three phase
1.0 power factor
Efficiencies (excluding excitation)
—alternator .....98.63 per cent
—propeller motor .....98.4 per cent

Propulsion turbines
No. .....Two
—Type .....Cross-compound reheat, dual line
—Rating, each .....113,720 kw
—"A" line consists of .....Eleven-stage H.P. cylinder
Three-stage section of I.P. cylinder
Six-stage twin-flow L.P. cylinder
—"B" line consists of .....Twelve-stage section of I.P. cylinder
Six-stage twin-flow L.P. cylinder
—Inlet steam .....1,500 psig
1,000 deg F
—Reheat to .....1,000 deg F and 375 psia

—Vacuum .....29.0 in Hg
—Sea water temp. .....60 deg F
—Final feed water temp. .....435 deg F

Consumptions—
Total alternator output, per turbine .....113,720 kw
Heat consumption at alternator terminals .....8083.3 Btu/kw hr
Steam consumption at alternator..6.650 lb/kw hr
Heat consumption at propeller shaft .....6128.2 Btu/shp-hr
Assume:—calorific value of fuel 18,500 B.T.U. per lb. and boiler efficiency of 88 per cent
Estimated specific fuel consumption .....0.376 lb/shp-hr
Feed heating particulars—
The following figures are based on:—
Three H.P. heaters, deaerator, two L.P. heaters and drain cooler, the H.P. heater drains being cascaded to the deaerator.

Place	Pressure at heater (psia)	Heat Content, Btu/lb	Feed Temp., deg F
Initial	—	1488.05	—
H.P. exhaust (to reheater and No. 6 heater)	404.6	1360.6	435
I.P. initial (from reheater) ..	—	1522.4	—
7th I.P. (No. 5 heater)	152.1	1425.0	350
11th I.P. (No. 4 heater)	80.0	1361.0	301
15th I. P. (deaerator)	37.5	1293.0	263.8
2nd L. P. (No. 2 heater)	14.88	1220.0	202
4th L.P. (No. 1 heater)	4.85	1145.0	150
Condenser	29.0 Vac.	1029.9	—

Excitation requirements (continuous)
—Alternator at sliprings) each .....200 kw
—Propeller motor (at sliprings) each .....252 kw

Excitation sources (continuous)	
—Alternator main exciter, each	420 kw
—Propeller motor silicon rectifier cubicle, each (d.c.)	660 kw
Lubricating oil requirements	
—Propulsion turbo-alternator set, each	550 gpm
—Propeller motor	Self lubricating
Cooling water requirements, totals	
—Alternator air coolers	2000 gpm
—Propeller motor air coolers	2900 gpm
—Turbo-alternator set oil coolers	400 gpm
—Main exciter air coolers	240 gpm
Auxiliary power requirements (at sea), totals	
—Propeller motor excitation (a.c.)	1375 kw
—Propeller motor vent'n. fans	225 kw
—Main lub oil pumps	100 kw
Total	1700 kw

These figures, put forward by one of the foremost electrical manufacturing companies, are quite remarkable when considered from the viewpoint of the marine engineer, although probably not so striking to the power-generation engineer ashore. Nevertheless, the steam rate and specific fuel consumption show the advantage of generating in very large units.

Weights, totals	
—Turbines—"A" lines	440 tons
—Turbines—"B" lines	340 tons
—Alternators	744 tons
—Auxiliaries for above	35 tons
—Propulsion motors	1050 tons
—Control gear	50 tons
—Alternator exciters	36 tons
—Propulsion motor rectifiers	15 tons
Total	2710 tons

A criticism which has always been levelled at turbo-electric machinery is that of weight, but the figure of 2,710 tons represents the remarkable figure of 110 shp per ton. On the all important matter of cost, it is believed that such machinery could be produced at a realistic price per installed shp. What could the advocates of a comparable geared turbine installation offer as an alternative?

B. F. Goodrich

Cutless Bearings

OIL RESISTING RUBBER

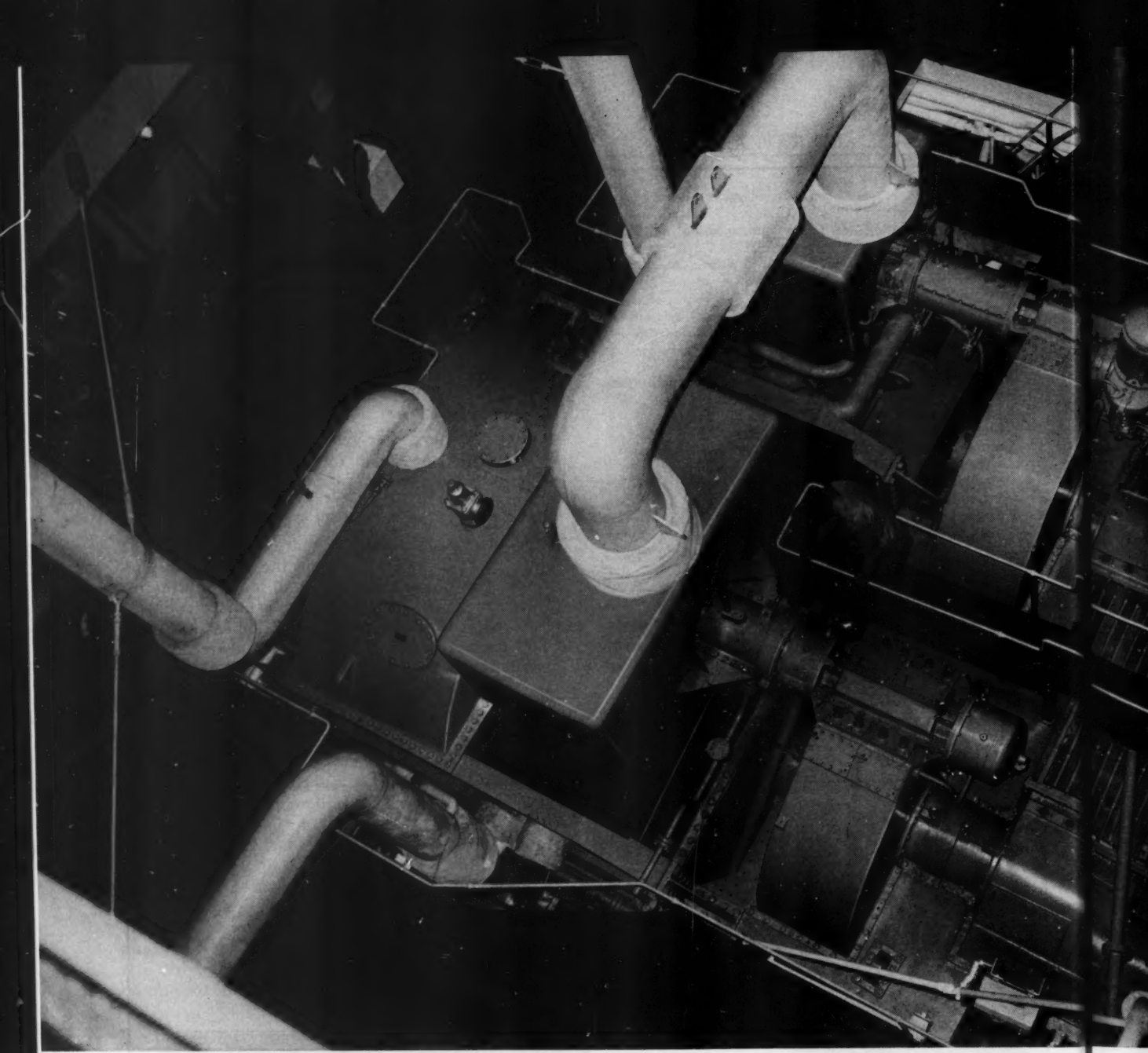
FOR PROPELLER SHAFTS

There is a size and type of Cutless Bearing for every powered boat or vessel.
Soft rubber, water lubricated, Cutless Bearings out-wear all other bearing materials.

LUCIAN Q. MOFFITT INC.

AKRON 8, OHIO

Engineers and National Distributors



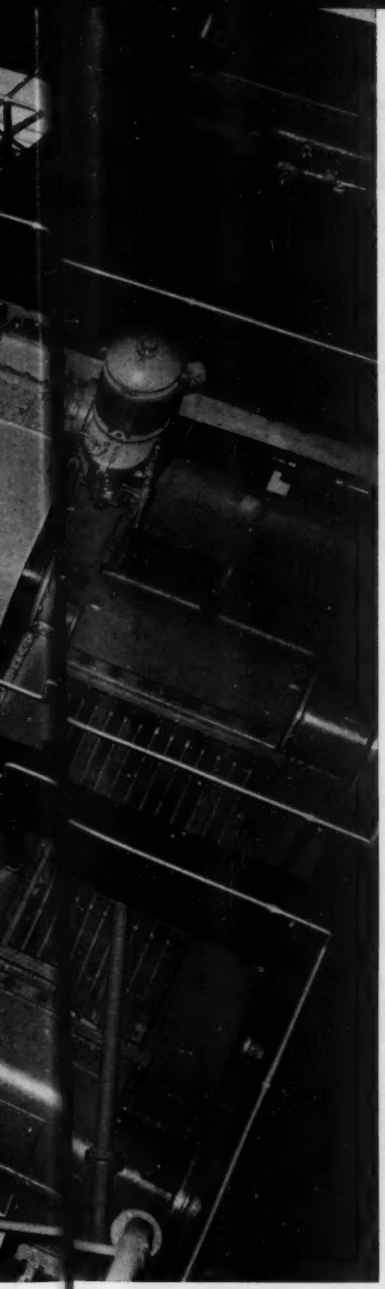
IN THE GLEAMING ENGINE ROOM OF *PENNSYLVANIA SUN*, Westinghouse geared turbine develops 18,500 shp to speed the new tanker over the seas.

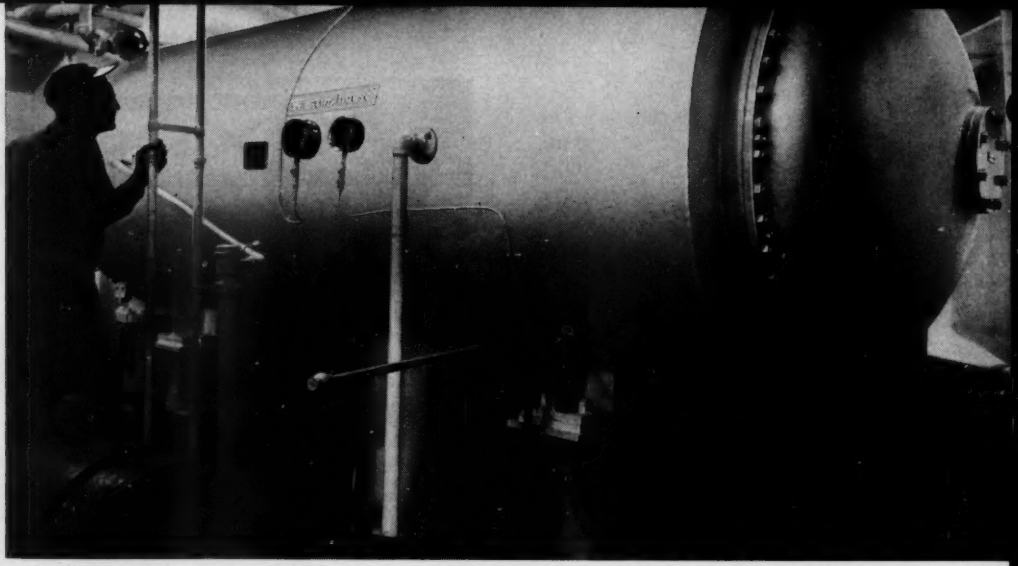
Half a century's experience proves dependability

In 1909, Westinghouse built America's first successful marine reduction gear . . . equipped the first geared turbine ship in 1911. Since then, Westinghouse has been a leading source of main propulsion, reduction gearing and related equipment to meet the marine industry's rigid requirements.

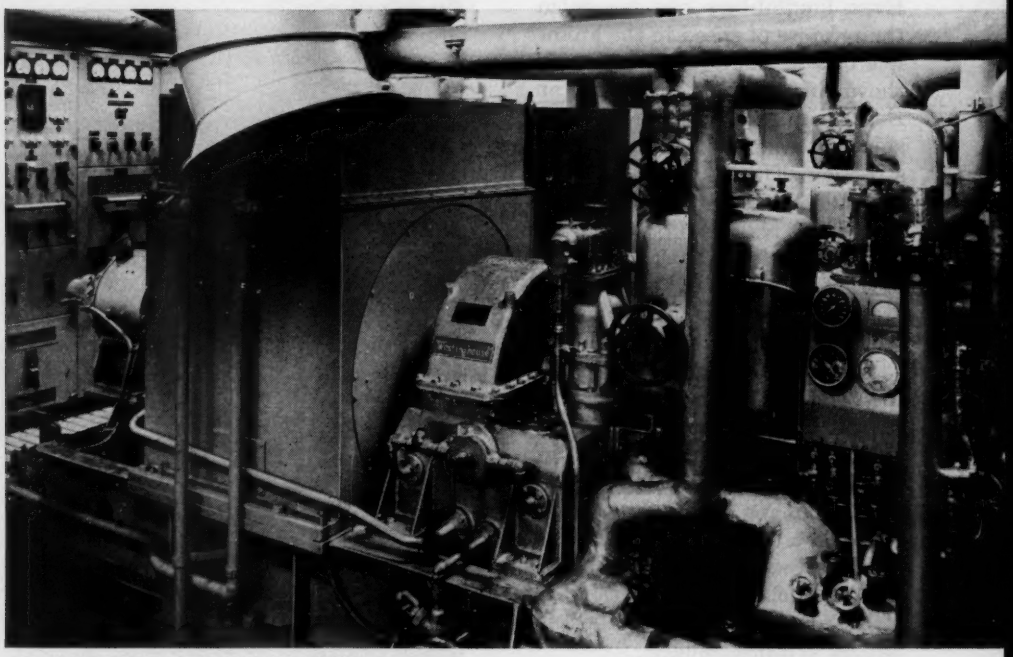
For example, the *UNITED STATES*, powered by Westinghouse, has held the Atlantic speed record for eight years. She has logged more than a million miles at 30 knots or better without a minute lost due to engine trouble. The Westinghouse-equipped *PRESIDENT GARFIELD* holds the Pacific record, speeding across 6300 miles in less than 13 days.

Two of the latest ships having Westinghouse marine equipment are the *PENNSYLVANIA SUN*, queen of Sun Oil Company's tanker fleet, and the *MORMACPRIDE*, new Moore-McCormack freighter. The *SKATE*, *NAUTILUS* and other nuclear subs cruise millions of undersea miles with reliable, trouble-free Westinghouse propulsion turbines, gearing, turbine-generators and auxiliary equipment.





ABOARD *PENNSYLVANIA SUN*, a single Westinghouse auxiliary condenser (3090 sq ft) collects exhaust from the two ship service turbine-generators.



ABOARD THE *MORMACPRIDE*, a passenger-carrying cargo ship: one of the two 600-kw Westinghouse ship service turbine-generator sets.

# of Westinghouse marine equipment

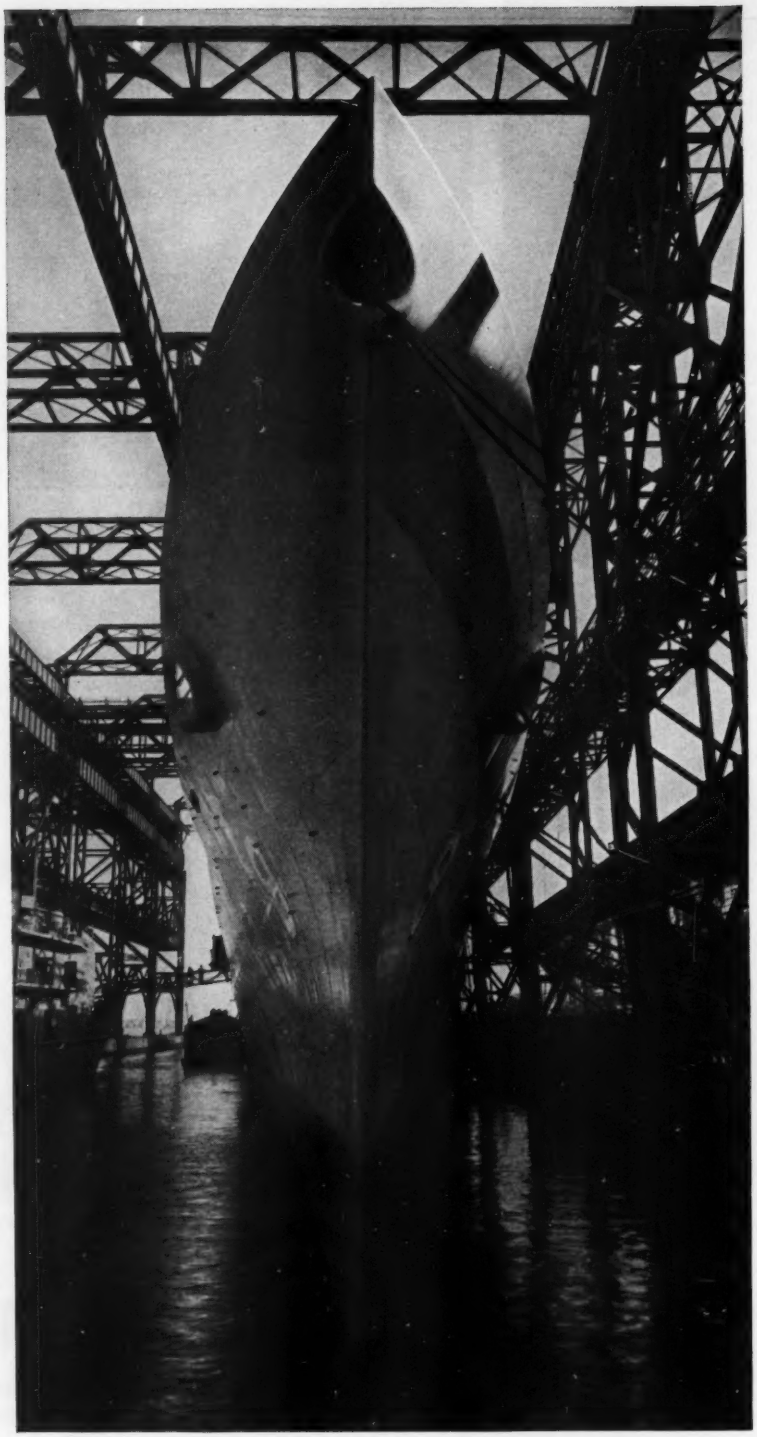
Behind the continuing superior performance of Westinghouse marine equipment: a massive research investment. From Westinghouse research have come new gear designs, better turbine blading materials and remarkable motor and generator insulations. Westinghouse efforts to reduce submarine equipment noise promise new, more efficient propulsion apparatus for all ships at sea.

Westinghouse record as a leading supplier of long-lasting, low-maintenance equipment for merchant and naval ships is your assurance of top quality and performance. A call to your Westinghouse representative starts a coordinated planning and manufacturing program so that your equipment is perfectly matched, electrically and mechanically.

Westinghouse Electric Corporation, P.O. Box 868, Pittsburgh 30, Pennsylvania. J-92050

Westinghouse

SHE'S BUILT FOR SPEED



Even landlubbers can recognize the promise of speed in the knife-like bow of the *USS Long Beach*, shown in an outfitting basin at Bethlehem Steel's Quincy, Mass., shipyard where she's under construction. This 721-foot, 14,000-ton guided-missile cruiser will be the U. S. Navy's first nuclear-powered surface ship . . . capable of higher sustained speed and greater cruising range than any vessel now afloat.

Within a few hundred feet of the *Long Beach*, though not visible in this picture, another distinctive naval craft is taking form in the Bethlehem yard. She's the 7,600-ton *USS Bainbridge*, scheduled to be the U. S. Navy's first nuclear-powered, guided-missile frigate. She, too, will be capable of high speeds and virtually unlimited cruising range.

The completion of these nuclear-powered ships marks the beginning of a new era in shipbuilding, one that calls for the cumulative skills and talents of Bethlehem Steel . . . for more than 50 years a leading builder of ships for the U. S. Navy.

SHIP REPAIR YARDS

Boston Harbor — New York Harbor
Baltimore Harbor — Beaumont, Texas
Los Angeles Harbor — San Francisco Harbor

SHIPBUILDING YARDS

Quincy, Mass. — Beaumont, Texas
Sparrows Point, Md. — San Francisco, Calif.

BETHLEHEM STEEL
Shipbuilding Division
GENERAL OFFICES: 25 BROADWAY, NEW YORK 4, N. Y.
Telephone: Digby 4-3300 Cable Address: BETHSHIP

"JOURNAL OF THE INSTITUTE OF FUEL"

NUCLEAR POWER FOR SHIP PROPULSION

ACKNOWLEDGMENT

This article was written by J. E. Richards, Ph.D., head of Atomic Energy Section British Shipbuilding Research Association. It was presented at a meeting of the Institute of Fuel in March 1960 and is reprinted from the June 1960 issue of "Journal of the Institute of Fuel."

INTRODUCTION

THIS DISCUSSION of nuclear power for ship propulsion is restricted to the merchant-ship application and is concerned with the possible development of a new means of propulsion which may prove to be more attractive economically than oil fuel, at least for certain types of ship. Bearing in mind the difficulty which exists in establishing small nuclear power stations competitive with those burning fossil fuels, it is possible that it will be many years before nuclear power makes any appreciable impact on our merchant fleet. For large ships there may be a gradual change over to nuclear propulsion, but it does not seem likely that this process will be rapid or will extend to smaller vessels, unless there are new developments which give nuclear power the promise of being more economical than conventional machinery by a substantial margin.

There are many factors involved in this application of nuclear power, but rather than cover the subject in a general way it seemed appropriate to give a short appraisal of the present position and to follow this by a more detailed consideration of nuclear fuel and fuel cycles which may be used for this application.

TYPE OF SHIP

Some idea of the production of marine engines in this country can be seen from Table I in which is given the number of main engines completed between April, 1956, and April, 1957, for ships over 100 tons gross and 120 shp. It will be seen that most of the main engines are of less than 10,000 shp but it should be mentioned that the number in the 15,000-20,000 shp category is increasing because of the trend towards larger tankers. At present there seems little hope that nuclear power will be economically attractive for outputs of less than 20,000 shp and the possibilities are therefore limited at present to large oil tankers and fast passenger liners. Because of the potential hazards with nuclear propulsion, it seems unlikely that nuclear propulsion will be applied to passenger vessels until there has been considerable experience with this new form of propulsion and consequently attention is almost entirely confined to large tankers at present.

Large tankers are used for the carriage of crude oil and in general the cost of transport of oil decreases with the increase in size of tanker. Limitations are imposed by draft restrictions at terminal ports and by the Suez Canal. At the present time

TABLE I—*Marine Main Engines Completed between April, 1956, and April 1957*

S.H.P. of the Main engines	Steam		Oil engines	Total
	Recip.	Turb.		
Up to 5,000	17	—	326	343
5,000 to 10,000	—	28	43	71
10,000 to 15,000	—	19	1	20
15,000 to 20,000	—	12	—	12
20,000 to 25,000	—	5	—	5
Over 25,000	—	—	—	—

the largest tankers under construction in this country are of about 65,000 tons deadweight and of 20,000-22,000 shp. The 65,000 ton deadweight tanker may well be the first application of nuclear power in a British merchant ship and most of the studies which are now being made are centered on this type of ship with a shp of about 20,000.

During recent years there has been a rapid increase in the number of large tankers on order and in service throughout the world. In July, 1956, there were eight vessels over 40,000 tons deadweight in service or launched and 79 being built or contracted. The corresponding figures for January, 1957, were 21 and 190 respectively, and for July, 1957, 47 and 347 respectively.

TANKER ECONOMICS

Studies have been made of the economics of tanker operation as this subject is very relevant to an investigation of types of reactor for this application. The approach which has been adopted in the B.S.R.A. investigations has been to compare a nuclear-powered tanker with a conventional vessel of the same deadweight. It has been assumed that the service speed of the nuclear tanker is the same as that of the conventional vessel of the same deadweight since the investigation showed that, unless nuclear fuel costs and machinery costs are reduced to a very low level, any increase in speed is unlikely to be justified. The main variables in the economic analysis are the cost of the reactor and the annual fuel cost. Recent estimates of reactor weights for 20,000 shp output give figures ranging from about 1,500-2,000 tons and a nuclear-powered 65,000 ton tanker with this range of reactor weight has roughly the same carrying capacity as the conventional vessel.

Other factors such as the reduced frequency of refuelling of the nuclear vessel do not have any noticeable effect on the economics and a good assessment of the attractiveness of the nuclear ship can be obtained by investigating whether the saving in the annual fuel bill will justify the additional machinery cost arising from the amount by which the cost of the reactor exceeds that of the conventional boilers.

A rough comparison on these lines for 65,000 ton deadweight 20,000 shp tankers is given in Figure 1 on which two lines are drawn corresponding to oil-fuel prices of 120s. and 150s. per ton and these lines represent the break-even lines for nuclear propulsion to have economic parity with conventional machinery.

Capital charges of 15 per cent were assumed and these included depreciation, return on capital investment and insurance. The oil-fuel price of 120s. per ton is the present-day average between U.K. and Persian Gulf ports. It is generally thought that the cost of oil fuel at present is somewhat depressed and as the economic attractiveness of nuclear ships is strongly influenced by the cost of conventional oil fuel, the effect of a price increase to 150s. per ton is also indicated on Figure 1. It seems unlikely that this latter price will be exceeded in the next 10-20 years unless there is a disarrangement of supplies.

It will be seen from Figure 1 that on the basis of present-day oil-fuel costs the maximum cost which can be justified for the reactor is of the order of £1¼ million if the nuclear fuel cost were zero. This maximum cost falls off to nothing at the point where nuclear-fuel costs equal oil-fuel costs.

Nuclear propulsion will be attractive commercially only if the reactor and fuel cycle selected show potential for development which will lead to reduction in both capital and fuel costs below the line indicated in Figure 1. The need to reduce nuclear fuel costs leads to a study of the alternative fuel cycles and for a reactor to have some potential for capital-cost reduction the size of the system must be small, there must be some limitation on the use which is made of expensive materials, and manufacturing costs must be low.

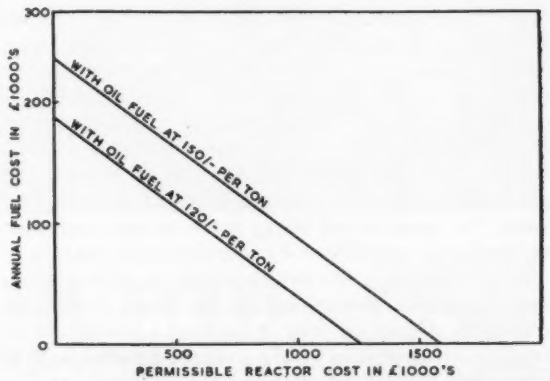


Figure 1. Permissible reactor cost to achieve economic parity with conventional machinery for 65,000 ton d.w. tankers on Mena-Canal-U.K. route.

NUCLEAR FUEL CYCLES

The use of nuclear fuel is much more complicated than that of fossil fuels because of the expenses incurred in the fabrication and chemical processing of the fuel elements and the interest on the capital invested in nuclear fuel. Thus although from a long-term point of view it is important to make the highest possible utilization of nuclear fuel, the requirement from a short-term point of view is to use a fuel cycle which will give the lowest overall fuel cost and this may not necessarily correspond to the highest utilization.

This point may be illustrated by referring to the nuclear-power-station program in this country. The graphite-moderated natural-uranium reactors are expected to achieve a fuel utilization of perhaps one-half per cent by the time the fuel elements are removed and this might be extended to perhaps 2 to 3 per cent by recycling the plutonium recovered from the spent fuel. It is, however, doubtful whether it will be economic to recycle plutonium in these reactors especially as it seems likely that the price of natural uranium will fall in the next few years. Thus it may be preferable to think of these natural-uranium reactors as consumers of natural uranium and producers of civil plutonium and to consider the most economic use which can be made of this secondary fuel.

The best utilization of civil plutonium would probably be obtained in a fast reactor but the practicability and economic attractiveness of this scheme has not yet been established. Another possibility might be to use it in a reactor of the high-temperature gas-cooled type using thorium as a fertile material. It might also be used for enrichment of natural uranium in various types of thermal reactors. The major difficulty in considering plutonium as a reactor fuel is that the nuclear properties are more complicated than those of uranium 235 and have not been established accurately. Also little plutonium has in the past been available for experimental studies. Consequently the present-day approach is to design reactors to use either natural uranium or uranium enriched in the 235 isotope in a diffusion plant, and to consider the use of plutonium for recycling or enrichment as developments which may take place in the future. Present-day estimates of the economics of feeding plutonium into slightly enriched uranium reactors are not likely to be very accurate and operating experience is required to substantiate such estimates.

From the point of view of the marine application the possible utilization of civil plutonium is of great interest because it may be available in large quantities in this country by about 1970 and because it is concentrated nuclear fuel and may permit small core sizes. Moreover the consideration of its use may lead to new reactor concepts better suited to the marine application. For this reason the B.S.R.A. Atomic Energy Team at Harwell has for the past year been making a study of the possible use of civil plutonium as a marine fuel and some preliminary thoughts on this subject are given in a later section of this paper. This work is, however, looking very much to the future but it may well be that only by a consideration of the future possibilities can a concept be produced which is potentially attractive to the ship owner.

In considering the present position regarding the possibility of applying nuclear power to marine propulsion attention has to be confined to reactor systems using enriched uranium fuel. There are a large number of possible reactor types and recently a number of firms and consortia in the United Kingdom have proposed designs for nuclear reactors for ships. [1]

TYPES OF REACTOR

Reactors for the marine application must be rugged and reliable. Complicated designs showing only marginal advantage over simpler concepts are not likely to be favored for the first nuclear-powered ships.

A general appreciation of the various alternative types of reactor burning slightly enriched uranium which have been proposed for marine application can be obtained by considering them in two classes: (*a*) the pressurized-water reactor and further developments of this type, and (*b*) the gas-cooled graphite-moderated reactor and more advanced gas-cooled types which can be considered to be derived from it. These two classes are now discussed separately.

The Pressurized-water Reactor

Hydrogen is a very efficient moderator and small cores are possible without excess neutron leakage but the absorption of neutrons by the hydrogen is sufficiently large for it not to be possible to use natural uranium.

The pressurized-water reactor was first developed in the United States for submarine propulsion and for this application highly enriched fuel is used which is far from being economic. The design of a reactor of this type but of a larger output and more economic was initiated in the United States for an aircraft-carrier project and this design formed the basis of the nuclear power station at Shippingport, which has now been in operation for nearly two years. The reactor core contains natural-uranium seed besides the highly enriched fuel and the seed fuel elements are in the form of uranium oxide pellets in zirconium alloy cans. Although the burn-up of these seed elements obtained to date is limited, loop tests indicate that a burn-up of at least 10,000 MW-days of heat per ton may be possible with this type of fuel element. This is much larger than is expected from uranium metal fuel elements and oxide fuel has been proposed in most of the recent

design studies of marine reactors, both liquid-and gas-cooled. Uranium oxide has the advantage that a large proportion of the fission products are retained at a high temperature and it is compatible with the water coolant. Also, the rate of leaching out of fission products from the reactor of a sunken ship may be expected to be very low.

In order to achieve reasonable steam temperatures the primary circuit pressure of a pressurized-water reactor is usually of the order of 2,000 psi and this high pressure is one of the disadvantages of this system. Another disadvantage is the need for stainless steel in the primary circuit. The capital cost of this type of reactor appears to be very much higher than the sum which can be justified from the economic standpoint, and it is difficult to see how the capital cost of this type of reactor can be reduced except through developments leading either to boiling being permitted in the core with a reduction in circuit pressure to about 1,000 psi, or by the use of an organic liquid instead of water permitting pressures of about 200 psi or less.

There are, however, uncertainties connected with the use of both the boiling-water and organic-liquid systems. With the boiling-water system there are doubts about the control of the reactor when subject to ship motions and it may well be that the amount of boiling which can be permitted is severely limited. Only a small amount of experience has so far been accumulated on the behavior of organic liquids in nuclear reactors and although loop tests have been favorable there remains the possibility that during operation, particularly under fault conditions, deposits of polymer may accumulate on the fuel element surfaces. Much more operating experience is required before there can be complete confidence in this type of reactor.

Graphite-moderated Reactor

This type originated from the original Calder Hall design and in its most advanced form, i.e. A.G.R., uranium oxide fuel elements similar to those adopted for the water-moderated systems are proposed. The use of heavy water, light water, beryllium oxide and zirconium hydride have been proposed in place of the graphite and in some of these alternatives such as the heavy-water-moderated system, steam cooling may be preferred in that it leads to a reduction in the size of the heat exchanger and may allow decay heat to be removed without the operation of a mechanically driven pump or blower.

The advantage of this class of system over the pressurized-water type is that it has promise of high-temperature operation and good thermal efficiencies. Temperatures high enough for the use of a gas turbine drive to be contemplated may eventually be achieved and it is interesting to note that a study of high-temperature reactors of this general type for marine propulsion is being made in the United States by the General Dynamics Corporation under contract from the Maritime Commission. A recent report [2] of this study indicates a preference for graphite moderation and helium cooling.

The potential attractiveness of the gas-cooled graphite-moderated reactor would appear to depend on the degree of enrichment of the fuel. If a very low enrichment is necessary to achieve low fuel cost the size of the graphite system would tend to be too large for marine use. Also the moderator temperature coefficient of reactivity would probably be positive and this is not a desirable characteristic.

ASSESSMENT OF REACTOR TYPES

Fuel Costs

The slightly enriched uranium fuel cycle entails enrichment of natural uranium in a diffusion plant, fabrication into fuel elements, chemical processing of used fuel to recover the plutonium produced for which credit is given and also of the depleted uranium which also has some value and is returned to the diffusion plant for enrichment. Until this fuel cycle is being used in this country on a fairly large scale it will not be possible to estimate the costs accurately, but the indications are that the total cost of fuel for any marine reactor using this fuel cycle is not likely to be much below that of oil fuel. Moreover, because accurate estimates cannot be made of the rate of build-up of the plutonium isotopes it is not possible to assess accurately the initial enrichment for the required burn-up of the fuel. Also it is not possible to say categorically that one reactor type will give a lower fuel cost than another, although in general the reactor requiring enrichment of say 2 per cent would give a lower fuel cost than that requiring 4 per cent enrichment, because the cost of the uranium burnt would be less and also the fuel investment cost for the higher enrichment would be much larger unless the heat rating was much increased.

Recycling the plutonium produced is expected to reduce fuel costs to some degree, as also is the use of civil plutonium for enrichment, but if the price of plutonium is set by its equivalence to uranium 235 as a means of enriching natural uranium for use in thermal reactors, this reduction may be small.

Capital Costs

The situation with regard to capital cost is a little clearer than for fuel costs for those reactors such as the pressurized-water, indirect-cycle boiling-water reactor and organic-liquid reactor for which a good estimate of the core size and of the engineering features can be made. The eventual cost of the boiling-water reactor may be expected to be slightly less than that of a pressurized-water reactor but perhaps the organic-liquid reactor shows most hope of reducing capital costs to the required level.

The core size of the graphite-moderated system of the A.G.R. type having a reasonable enrichment

probably lies between 14 and 18 feet over the reflector and because of its large size the capital cost of this reactor may be expected to make it unattractive. The capital cost of more advanced types such as the heavy-water-moderated gas-cooled system and the high-temperature graphite-moderated system are more difficult to estimate but it may well be that the capital cost of some of these more advanced gas-cooled systems will, with development, fall to the required level.

Safety

The Minister of Transport has appointed a committee to advise him generally on the safety problems arising from nuclear propulsion in merchant ships at sea and in port and this subject was discussed at the International Convention for the Safety of Life at Sea which was held this year. For nuclear reactors as we know them at present there is no doubt that containment will be required and that the safety of the nuclear-powered ship will depend on such containment being designed to a standard that there is virtually no chance of a breach by any accident which is likely to occur in ports or coastal waters.

It seems reasonable to expect that successful operation experience of a reactor of the same type on land will be desirable. This limits the choice of reactors available at present and in the near future. Reactors of which operational experience will be obtained in this country in the next few years are the A.G.R., possibly a steam-cooled heavy-water-moderated reactor and the high-temperature gas-cooled system. For the pressurized-boiling-water and organic-liquid reactors one might have to rely on prototype experience in the United States and for these types a case can be made for making use of American technology for the first ship. A land-based prototype reactor of one of these types could be built in this country but as already mentioned it is not possible to see clearly the economic development potential of any of these systems.

Although it may well be that one will always have to rely to some extent on containment, there is a strong case for research and development leading to reactor systems inherently much more safe than present types.

Liquid-moderated systems with good safety characteristics can be designed but for the ultimate accident, in which there is a total loss of coolant from the primary circuit, there is the possibility that some of the fuel may melt and this appears to be so in the *Savannah*. [3] The chances of such a type of accident, however, are very remote indeed but could arise from a high speed collision in which the containment and primary circuit were breached.

From a theoretical point of view there is a lot to be said for using a solid moderator, if suitable negative temperature coefficients of reactivity of the moderator and fuel can be obtained, for decay heat and perhaps also excess heat under transient conditions could be stored in the moderator. Ultimate safety would appear to depend on the development of fuel elements which can retain the fission products at a very high temperature so that the heat can be removed by radiation.

CHARACTERISTICS OF CIVIL PLUTONIUM

Before discussing the possible use of civil plutonium as a marine fuel it is convenient to refer to the physical characteristics of this material. Although civil plutonium is often thought of as an alternative to uranium 235 for the enriching of natural uranium it is not generally realized that the nuclear properties of plutonium are markedly different from those of uranium 235 and that accepted methods of reactor calculation become suspect when applied to plutonium systems.

Production of Civil Plutonium

In the natural-uranium graphite-moderated civil-power reactors now being built in this country about 0.8 neutrons will be absorbed in the uranium 238 to form plutonium 239, per neutron absorbed in the primary fuel uranium 235. As the reaction continues the concentration of plutonium 239 in the core builds up and the concentration of uranium 235 decreases as shown in Figure 2. [4] Neutrons are absorbed in the plutonium 239 and about two-thirds of these absorptions cause fission to take place and about one-third lead to the production of the higher isotope plutonium 240. Plutonium 240 is not fissile by thermal neutrons but captures the neutron to form plutonium 241 which is. About 80 per cent of the neutrons absorbed by plutonium 241 cause fission and the other 20 per cent lead to the production of plutonium 242 which is not fissile by thermal neutrons. The variation of concentration of the plutonium isotopes in natural-uranium graphite-moderated systems is also shown in Figure 2 and after an irradiation of 3,000 MW-days per ton of natural uranium the plutonium present is expected to have a concentration of about 80 per cent plutonium 239, 16 per cent plutonium 240, 4 per cent plutonium 241, and a negligible amount of plutonium 242. This plutonium will be abstracted from the fuel elements by chemical processing and is the material which is expected to be available late in the 1960s and which is generally referred to as civil plutonium.

Heat Content and Initial Reactivity of Civil Plutonium

The small plutonium 241 content does not make any great contribution to the initial reactivity which depends mainly upon the number of neutrons produced per thermal neutron absorbed in the uranium 239 and on the fraction of these neutrons whch are absorbed in the plutonium 240. Although

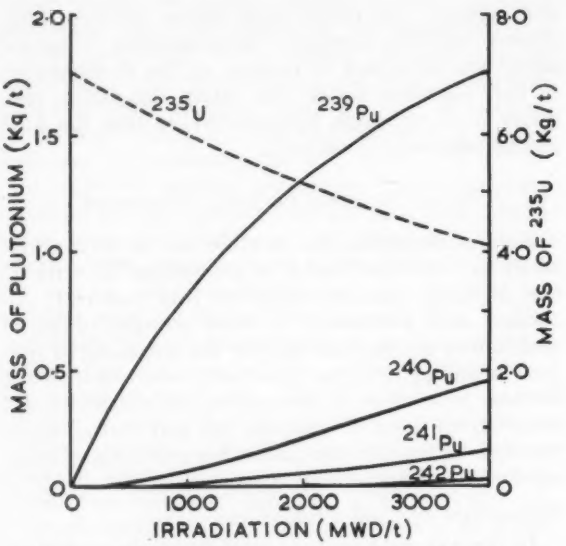


Figure 2. Variation in the concentration of plutonium isotopes in a uniformly irradiated Pippa-type reactor.

it can be seen that, provided the extraneous charges are not high, there is a possibility that a plutonium-burning reactor would function with low fuel cost. The number of neutrons produced per thermal neutron absorbed in plutonium 239 lies between about 2.0 and 1.8, falling with increase in moderator temperature. It can be shown that in a large plutonium-burning reactor having a feed of civil plutonium the equilibrium value of the number of neutrons produced per thermal neutron absorbed in the plutonium isotopes is of the order of 1.35. One neutron is required to continue the reaction so it will be seen that the amount of new plutonium which can be regenerated in a civil plutonium-uranium 238 system is likely to be fairly small. This is one of the reasons why B.S.R.A. studies of the possible use of civil plutonium as a marine fuel have been confined in the first instance to the burning of this fuel without regeneration.

It can be shown that, on the basis of the attainment of equilibrium concentrations of the plutonium isotopes in a large civil-plutonium-burning reactor, the calorific value of the civil plutonium is about 830 megowatt-days of heat per kilogram. Thus on a heat basis 1 gram of civil plutonium would be equivalent to 1.85 tons of oil fuel burned in a marine boiler (18,500 Btu/lb with a boiler efficiency of 88 per cent). The value of this plu-

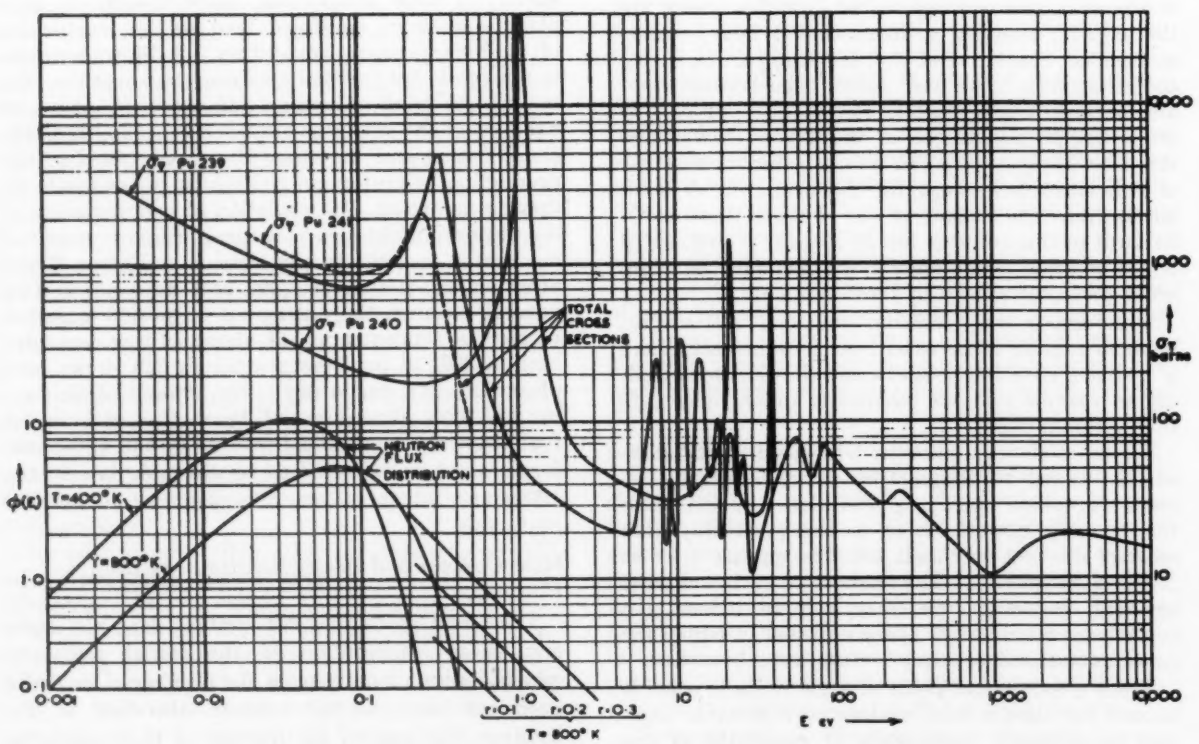


Figure 3. Thermal flux distributions and plutonium cross-sections.

tonium is estimated at present on its equivalence to uranium 235 as a means of enriching natural uranium for feeding into an A.G.R.-type reactor and a figure of £5 per gram has been quoted. [5] So if the fabrication, chemical processing and fuel element investment charges can be reduced to a negligible amount the price of the oil fuel equivalent on a heat basis to civil plutonium at £5 per gram would be 54s. per ton. The actual price of marine fuel oil is at present 120s. per ton so it can

PLUTONIUM-BURNING FUEL CYCLE

Variation of Reactivity of Civil Plutonium with Burn-up

In order to reduce the level of extraneous charges a long burn-up of the fuel is essential and consequently variation of reactivity of the fuel with burn-up is important.

It is necessary at this stage to refer to the total cross-sections of the plutonium isotopes and these are shown in Figure 3. It should be noted that the cross-sections of the higher plutonium isotopes have not yet been determined very accurately. The main features of Figure 3 are the broad resonance in the plutonium 239 cross-section at 0.3 e.v. and a high peaked narrow resonance in the plutonium 240 cross-section at about 1 e.v.

Also shown in Figure 3 is the form of neutron flux distribution per unit energy usually assumed in the calculations of well thermalized, slightly enriched uranium reactors. This consists of a Maxwellian distribution with average energy at or a little above that corresponding to the moderator temperature and a $\frac{1}{E}$ tail which represents the build-up in neutron density as they slow down into the thermal region. A joining function between the curves is sometimes included. Effective cross-sections can be obtained by multiplying the flux curve by the cross-section curve and obtaining an equivalent total cross-section assuming all the neutrons have a velocity of 2,200 meters per second corresponding to room temperature.

Values of these effective cross-sections have been calculated by Westcott [6] and selective values for two moderator temperature and epithermal components r=0, r=0.1 and r=0.2 are given in Table II. It will be seen that there is a gradual increase in the plutonium 239 cross-sections with temperature and epithermal fraction and a marked increase in the 240 cross-sections with increased epithermal fraction due to the increased absorption in the 1 e.v. resonance. In his paper Westcott points out that these effective cross-sections are likely to be inaccurate for under-moderated systems with high r values but the figures given in Table 2 form a convenient basis for making an initial appraisal of the variation of reactivity of civil plutonium with burn-up, normalized to the fall off in plutonium 239 concentration, as shown in Figure 4. It will be seen that the reaction rate of plutonium 240 and the rate of build-up of plutonium 241 are strongly influenced by the effective cross-section of plutonium 240.

From these isotopic concentration curves it is possible to make a rough estimate of the variation of reactivity on an infinitely large system (k_∞) with burn-up, and this is shown in Figure 5 for a hypothetical reactor in which there are 66 atoms of steel present per atom of civil plutonium and allowance is made for the neutron absorption in the fission products. It will be seen from Figure 5 that when r=0 the reactivity falls off in a manner sim-

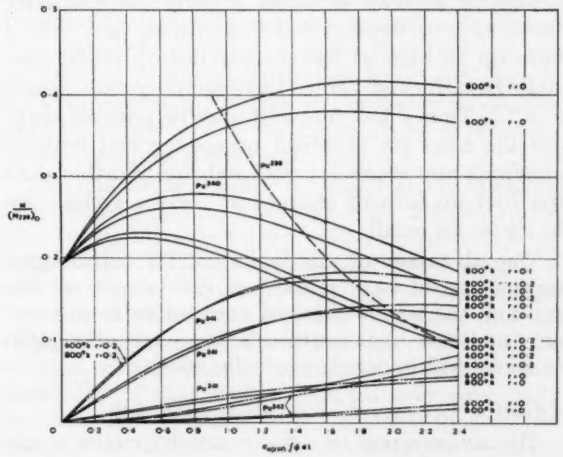


Figure 4. Change of isotopic concentration of plutonium with irradiation.

TABLE II.—*Effective Cross-sections (Barns)*

Mean thermal neutron temp.	600° K			700° K			800° K			2,200 meter/sec.
Epithermal component	r=0	r=.1	r=.2	r=0	r=.1	r=.2	r=0	r=.1	r=.2	Values
U_{235} fission	527	532	535	523	537	550	522	542	561	582
Pu_{239} fission	1,113	1,249	1,386	1,295	1,408	1,521	1,486	1,565	1,645	738
Pu_{239} absorption	1,708	1,956	2,203	2,015	2,220	2,425	2,355	2,499	2,642	1,024
Pu_{240} absorption	291	1,301	2,310	320	1,390	2,478	314	1,474	2,634	260
Pu_{241} fission	1,304	1,363	1,422	1,423	1,459	1,495	1,534	1,545	1,555	971.1
Pu_{241} a=1.365 f	1,708	1,860	1,941	1,942	1,991	2,041	2,094	2,108	2,123	1,326

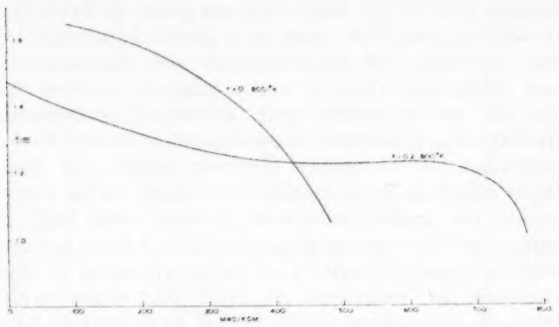


Figure 5. Variation of reactivity with burn-up.

ilar to that which may be expected with a uranium 235 burning reactor, but with the higher epithermal fraction and consequently higher absorption rate in plutonium 240 the reactivity curve is flattened. What is happening is that the plutonium 240 is acting as a burnable poison, reducing the initial reactivity and at the same time producing plutonium 241 which maintains the reactivity for an extended period.

The value of these results is that they show that it may be possible to obtain a fairly flat reactivity curve in a plutonium burning reactor and that a burn-up as high as 680 megawatt-days might possibly be achieved before the reactivity falls below $k_\infty = 1.2$. Thus a low fuel cost may be possible without the need for chemical processing and without assuming any credit for the used fuel. Furthermore the fuel investment charges of such a system are likely to be small.

The advantage of this fuel cycle for marine propulsion would be that the fuel cost would not depend on the achievement of extreme neutron economy and that high neutron leakage and absorption in structural materials could be allowed.

Effective Cross-section of Plutonium 240

The achievement of a flat reactivity curve would depend on a high rate of neutron absorption in plutonium 240 and it will be seen from Figure 3 that this means that the absorption in the 1 e.v. resonance must be high. Although a detailed investigation has not been made of other moderators it seems likely that this high-resonance absorption can be most easily achieved with graphite moderation. This is because the maximum energy loss per collision is much smaller than with other moderators so that a larger fraction of the neutrons are slowed down into the resonance. The use of graphite as a moderator was thought to be an advantage from the point of view of safety in that it might provide a large heat sink and for this reason the more detailed investigation which is being made by B.S.R.A. into plutonium burning is being confined to the use of graphite as a moderator. Steel is considered as a structural materal.

APPLICATION TO MARINE PROULSION

Although civil plutonium will not be generally available for some years to come and though its price is uncertain, it seemed well worth while making a more detailed study of the plutonium-graphite system specifically for marine propulsion because it is a simple system and should the present estimate of the price of civil plutonium be realistic then this fuel cycle will have economic promise. In addition it would have an advantage over the present concept of an H.T.G.C. reactor in that an appreciable amount of structural material could be tolerated in the core and in particular that stainless steel fuel elements could be used; also at a later date ceramic materials such as silicon carbide which have promise of retaining fission products at a really high temperature could be employed. The development could possibly lead to high temperatures and to the use of gas turbines. It would be a system with considerable potential for development and the neutron economy could conceivably be increased by the use of thorium or depleted uranium blanket. Although calculations made on the basis of the Westcott cross-sections were useful in the initial work it was soon evident that a much more detailed calculation of the thermal neutron spectrum was necessary. The next stage of the work was to assume a heavy gas model of the moderator and, using an analysis given by Wigner and Wilkins, [7] calculate the thermal neutron spectrum for homogeneous mixtures of graphite, steel and civil plutonium. The main purpose of this work was to investigate the temperature coefficients of reactivity.

A typical result obtained is shown in Figure 6. About 90 energy intervals were taken between 0 and 1.3 e.v. and 90 simultaneous equations solved by means of a Mercury computer program to ob-

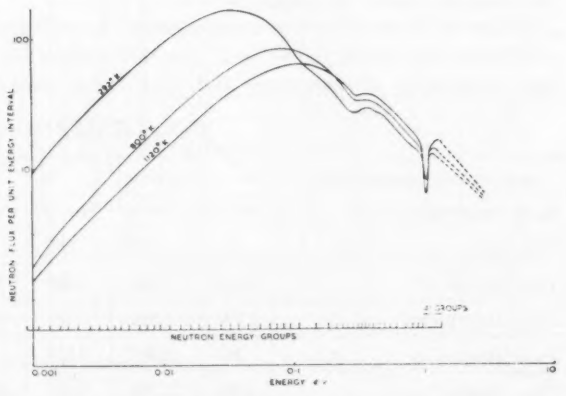


Figure 6. Neutron spectra for moderator temperatures of 292° K, 800° K and 1,120° K. Homogeneous case.

tain the neutron flux. It will be seen from Figure 6 that the flux departs considerably from the simple form assumed by Westcott and there are dips in the flux at 0.3 and 1 e.v. due to the resonance absorption in the 239 and 240 isotopes respectively.

It is not possible in this paper to give a detailed account of this work which has been extended to heterogeneous systems of stainless steel cermets in graphite in which appreciable self shielding of these resonances occurs.

The work is, however, very far from being completed but there are reasons for a certain amount of optimism and two effects have been uncovered which may lead to a very safe system of this general type being evolved. The first is that the broadening of the plutonium 240 resonance with increase in temperature, as shown in Figure 7, gives a negative temperature coefficient of reactivity of the fuel of the order of 1.5×10^{-5}. The other is that the increased back scattering of the neutrons with increase in moderator temperature gives under certain conditions an increased absorption in the 240 isotope with increase in moderator temperature, and there are indications that the overall moderator temperature coefficient would be negative. This second point is illustrated in Figure 8 which gives a

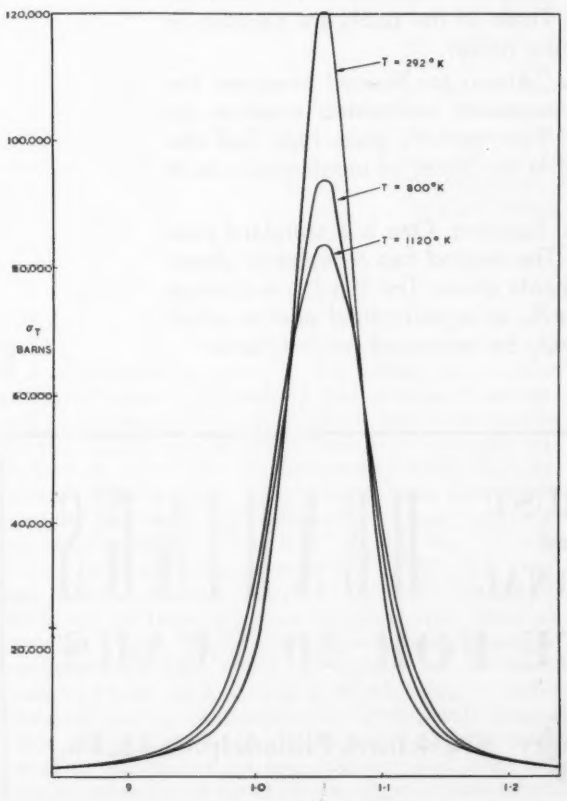


Figure 7. Cross-section of Pu 240 in the region of 1 e.v.

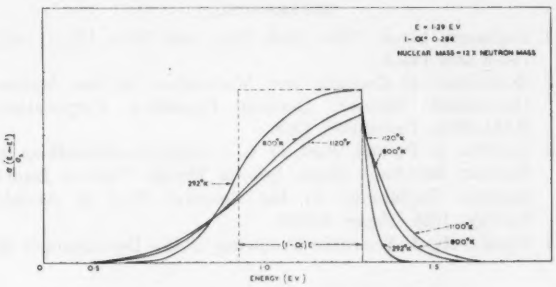


Figure 8. Scattering kernel at 1.29 e.v.

scattering probability curve for neutrons suffering collisions at 1.29 e.v. The curve gives the probability of a neutron's having a particular energy after making a collision with graphite, the energy of the neutron before collision being 1.29 e.v.

CONCLUSIONS

The general conclusion can be drawn that there is no clear line of development towards an economic reactor for merchant ships. There is at present a very slender basis for selecting a reactor type and probably potential for reducing capital costs is most important. The question as to whether fuel cost can be reduced to a sufficiently low level with slightly enriched uranium reactors will probably be decided only by experience of the operation of slightly enriched uranium reactors on land.

It is difficult to see how the development of slightly enriched uranium reactors for marine propulsion can be anything but slow and restricted to very large ships. While the successful development of fast reactors could conceivably lead to an increase in value of civil plutonium and thus favor the use of slightly enriched thermal reactors because of the consequent increase in plutonium credit, another possibility is that civil plutonium may eventually be cheap and plentiful. It is suggested that the results of the B.S.R.A. study illustrate the need for intensive research and development on plutonium-fueled systems.

ACKNOWLEDGMENTS

The author thanks the Council of the British Shipbuilding Research Association of the Director of Research for permission to publish this paper. He would also like to acknowledge the help given by various members of the staff of the Atomic Energy Research Establishment, Harwell, in the work being undertaken by the B.S.R.A. Atomic Energy team on the possible use of civil plutonium as a marine fuel. Members of the team principally concerned with this work are P. C. M. Kay, F. R. Allen, A. M. Brenan and A. Forbes-Gower.

REFERENCES

1. *Engineer, Lond.* 1959 (15th May and 22nd May), 207, 754–6 and 794–6.
2. Evaluation of Coolants and Moderators for the Marine Gas-cooled Reactor. General Dynamics Corporation. T.I.D.-4500, December, 1958.
3. Godwin, R. P., and Worf, D. L. Design Considerations in Nuclear Merchant Ships. Second United Nations International Conference on the Peaceful Uses of Atomic Energy, 1958. Paper P.1023.
4. Crockcroft, J. Scientific Problems in the Development of Nuclear Power, *J. Brit. nucl. energy Conf.*, 1957 (January), 2, S2.
5. Franklin, N. L., *et al.* Economics of Enrichment and of the use of Plutonium and U233. Second United Nations International Conference on the Peaceful Uses of Atomic Energy, 1958. Paper P.54.
6. Westcott, C. H. Effective Cross-section Values for Well Moderated Thermal Reactors. CERP-680.
7. Wigner, E. P., and Wilkins, J. E. Effect of the Temperature of the Moderator on the Velocity Distribution of Neutrons with Numerical Calculations for H as Moderator. Report AECD 2275.

GERMAN RESEARCH REACTOR FOR MARINE APPLICATIONS REACHES FULL POWER

The Babcock & Wilcox Company, designer and supplier of the major reactor components for the research marine reactor for the Kernenergie Hamburg, Germany, reported today that the test reactor has successfully reached its full rated power of 5000 kilowatts.

Consisting of a reactor core and four special-purpose pools, the unit is the largest of its type ever built. It is also the first European reactor to be built expressly for research in marine applications.

Owned and operated by Gesellschaft Fur Kernenergieverwertung In Schiffbau Und Schiffahrt (The Society for the Utilization of Nuclear Energy in Shipbuilding and Navigation) the research unit is 89 feet long and 29 feet wide. It is unique in that it has four pools—built in series—instead of the more conventional double pool. Three of the pools are capable of sustaining reactor operation at maximum power.

A feature of President Eisenhower's "Atoms for Peace" program, the reactor utilizes B&W-fabricated fuel elements containing uranium enriched to 20 per cent in uranium-235. The reactor's plate-type fuel elements contain this fissionable material in the form of uranium-aluminum alloy, 45 per cent uranium by weight.

Each of the four pools has a special function. One is a standard pool with beam ports and thermal column. The second has an exterior chamber for carrying out shielding experiments in air. The third is a storage pool for the reactor core, and the fourth, an experimental pool in which very large equipment and specimens may be immersed for irradiation.

KINGSBURY THRUST and JOURNAL BEARINGS
THE NAVY'S CHOICE FOR 40 YEARS
Kingsbury Machine Works, Inc. KINGSBURY Frankford, Philadelphia 24, Pa.

HILBERT SCHENCK, JR.

GRAPHICAL CHECKING OF TEST DATA

THE AUTHOR

was born in Boston, Feb. 12, 1926. Attended primary schools in the New England area and served two years in the Navy during World War II as an electronic technician. Attended Williams College receiving a B.A. degree, then Stanford University for an M.S. in Mechanical Engineering. Employed for four years as a test engineer in heat transfer research at Pratt and Whitney Aircraft. Joined the staff of Clarkson College, Potsdam, New York as an Assistant Professor and was recently promoted to Associate Professor of Mechanical Engineering. Author of several papers and books on underwater visibility, photography and diving plus the book Heat Transfer Engineering *recently published by Prentice-Hall, Inc.*

IN A PREVIOUS article [1] this writer discussed a graphical means of checking test data as it is generated by experiments on modern heat transfer apparatus. Such specialized graphical checks are important in a number of engineering fields. The so-called "Wilson plot", as an example, is commonly used by heat-exchange engineers to check for fouling resistances [2] while the "Willans line" is well known in steam turbine testing [3]. Although these and other specialized checking methods are amply discussed in basic engineering literature, little or nothing is said about certain specialized, graphical methods that can apply to almost all scientific tests in which an X-versus-Y relationship is under investigation. In this paper, the writer will discuss three of the most rapid and powerful graphic data-checks available to the test engineer and then discuss in some detail three simple experiments which will serve as examples of the methods.

THREE GRAPHICAL CHECKS

The most important and useful graphical transformation that can be applied to an X-Y function that is being generated by test is *rectification* (the selection of coordinate axes such that the data forms a straight line). Rectification is often achieved by the use of logarithmic or "semi-log" paper, by algebraic changes in the X and/or Y variables, or by a combination of algebraic transformation and axes changes. The techniques will not be discussed in detail here as they are well covered in several books [4] [5]. While straight-line plotting is usually stressed in engineering school at the freshman level (usually in a "graphics" course) it is seldom mentioned again to the student. As a result, the college junior or senior, who is performing lab tests which permit excellent application of graphic analysis, seldom, if ever, uses the methods. Further, modern texts in laboratory work [6] [7] give these potent diagnostic techniques only passing (if any) men-

tion. The rectification of test data yields the following benefits: The mathematical form of the function is immediately evident. The magnitude and severity of data scatter is obvious to all viewers of the plot. Straight-line data are most accurately extrapolated to known terminal points for checking. Statistical techniques of curve plotting and regression analysis are most extensively developed and easiest to apply when the function is a straight line [8]. Some of these advantages will become more evident in the examples that follow.

If a series of test points can be rectified, completely or partially, the resulting curve can often be extrapolated to a known limit-value and the complete data-set thereby checked for overall consistency. We will discuss two classes of *extrapolation checks*. Most familiar to engineers is *extrapolation to the lower limit of the independent variable*. An example of this "extrapolation check of the first kind" might occur during a test of pressure-loss in some kinds of hydraulic equipment. If we can rectify the curve of pressure loss versus flow, we know that this straight line should extrapolate to the origin. That is, we know that flow and loss should reach zero together.

The "second kind" of extrapolation check occurs when we *investigate by extrapolation the upper limit of the independent variable*. For example, we might be studying the effect of increasing temperature on heat loss in some kind of thermal apparatus. We expect that if we could increase temperature toward infinity, then heat loss would also approach infinity. Since direct plotting to this limit is impossible, we will usually plot the inverse-of-temperature versus the inverse-of-heat-loss and check the extrapolation of the line to the origin. The examples to be given will display both kinds of extrapolation checks in concrete terms.

AN EXPERIMENT IN TRANSIENT HEAT FLOW

In a senior engineering laboratory, an insulated stack having thermometers and thermocouples at various locations is subjected to the hot up-draft of a Bunsen burner located at the bottom of the stack. Figure 1 shows a plot of a thermocouple-reading

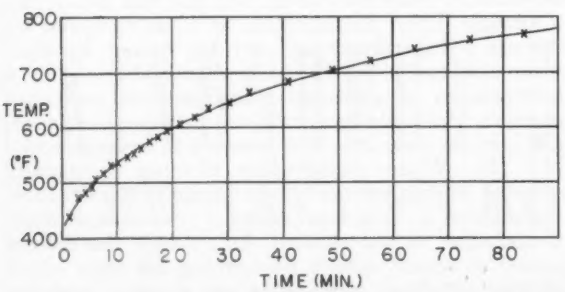


Figure 1: A plot of thermocouple reading against time-from-the-beginning-of-warm-up for a heated stack. The line through the points was drawn with a common French curve.

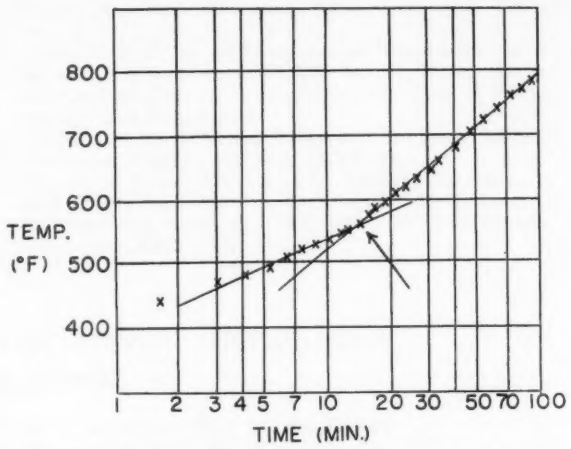


Figure 2: The same data as graphed in Figure 1 is shown, except that time is now plotted on a logarithmic axis. The lines are drawn with a straight-edge and the arrow shows the time at which the potentiometer range-change occurred.

against time-from-burner-light-off, as graphed on linear coordinates. After two years and several dozen student groups, it was noted that many of the curves seemed to have a dip or flat region around 500 to 550°F which no reasonable theoretical argument could explain. A simple change of coordinate axes soon solved the mystery, as shown in Figure 2. The data are approximately rectified in this case by plotting the log-of-time against temperature and the resulting curve reveals that the data falls into two groups, one below about 550°F and one above. Each data-family forms a roughly straight line on logarithmic coordinates but the two lines have entirely different slopes. Quite obviously, something happens at about 550°F that radically alters the test. An examination of the data-sheet revealed that at this point (indicated by the arrow in Figure 2) the potentiometer used to read the thermocouple outputs was changed from low to high range. This instrument defect had gone unnoticed for some time due to the difficulty of calibrating the potentiometer at the higher temperatures. Yet the data presentation in Figure 1 does not suggest that two different data families are involved, but only that the curve is not quite a smooth one. The benefits of rectification that are displayed in this simple example are equally applicable to the most refined experimental work.

A CLASSIC COLUMN TEST

It would be difficult to find a mechanical or civil engineer who has not performed some sort of test designed to study or verify the so-called Euler column formula

$$P/A = K\pi^2 E/(L/R)^2$$

where P is the maximum load the column can support, A its cross-sectional area, E the modulus of

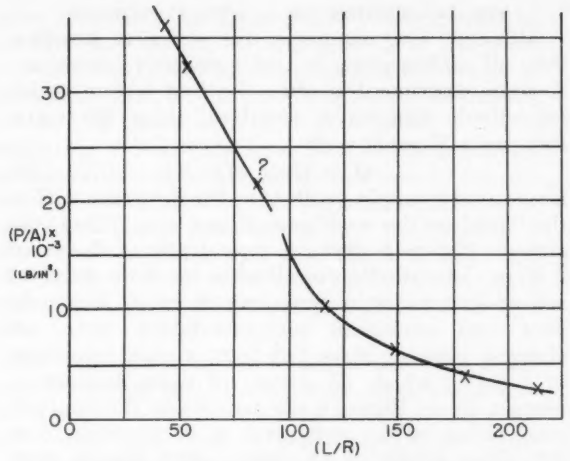


Figure 3: The maximum stress in seven ⅜ inch diameter aluminum rods is plotted against the "slenderness ratio" (length over radius-of-gyration). The lines shown are copied from a typical student report. The question mark identifies the column that might be in or out of the "Euler region" depending on how the points are connected.

elasticity of the material, L the length, R the radius of gyration, and K is a constant that depends on the end-conditions. But although this test has been repeated thousands of times, it is doubtful that a single student has ever *completely* analyzed his results. Inevitably the test results are plotted as shown in Figure 3, probably the worst graphic representation of these data that one could select. Yet we cannot blame the student, for this is the same presentation that he finds suggested in text or reference works [9]. The theory of slender-column stability suggests that the Euler equation will govern column failure at large L/R values, but that as the ultimate compressive strength of the column material is approached, the column begins to fail due to crushing. Thus the point at which the data deviates from the Euler theory is of considerable interest, and the plotting of two different curves as in Figure 1 is reasonable. But before considering better graphic methods for this simple analysis, let us first list the primary questions that any kind of analysis, graphic or mathematical, should answer here.

(a) Do our data follow the basic form of the Euler equation over a part of its range?

(b) Do our data give a reasonable estimate of the value at which deviation from the stability (Euler) criterion occurs?

(c) Do our data verify the exponent (−2) for the L/R ratio in the "Euler Region"?

(d) Do our data give a value of K that is consistent with end-conditions in the test?

(e) Do our data predict a reasonable value of ultimate compressive strength for the material?

(f) Do our data show a scatter and, if so, how great is this scatter?

(g) Do these data extrapolate to zero as L/R approaches infinity, thereby suggesting that it is consistent at the higher L/R end?

How well does the "traditional plot" (Figure 3) answer these questions? We might say that the outer four or five test points do seem to follow a general exponential curve so that (a) is tentatively answered in the affirmative. The answer to (b) is markedly effected by our choice of the French curve used to connect the points. If the question-mark-designated point belongs with the Euler points, then an L/R of around 85 is the critical value, but with the curve as drawn in Figure 3, we might select 95 as the L/R at which the Euler theory ceases to be useful. Questions (c) and (d) cannot be answered by this curve. Question (e) must not be answered since the extrapolation of the upper curve will yield a much too-high value for ultimate compressive strength of the aluminum used. Questions (f) and (g) are also wholly unanswerable by this data-presentation.

A much more useful way of graphing column data is to plot the log of (P/A) against the log of (L/R) as shown in Figure 4. From this curve we see that the answer to (a) is an obvious "Yes", for the straight line formed by the outer five points is proof of an exponential function. To question (b) we would give an answer of "yes" and estimate a critical L/R value of about 80. We see further that the doubtful point in Figure 3 definitely is part of the "Euler family" of points. To question (c) we again answer "yes" since a ruler quickly shows that the slope of the straight line is close to −2. (d) is not easily answered by this curve, but we can make a rough answer to (e). The upper curve appears to be going asymptotic to a log (P/A) value of about 4.6 which is a compressive stress value of close to 40,000 psi. The actual ultimate compressive strength of this material is listed at 43,000 psi so that this estimate is not too bad. To question (f) we say "yes, there is some scatter"

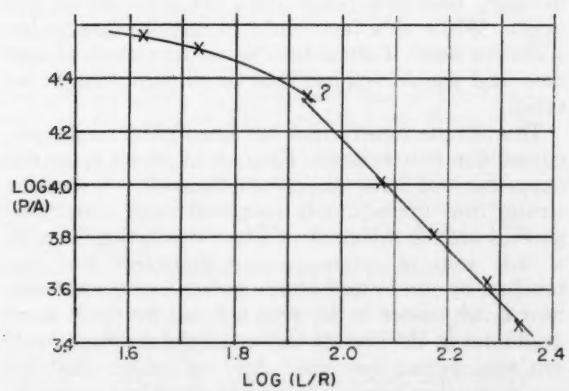


Figure 4: The same data shown in Figure 3 is replotted here on logarithmic coordinates. The doubtful point is clearly shown to be just within the "Euler region."

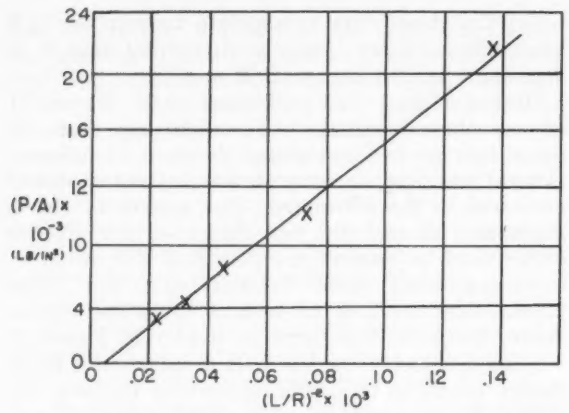


Figure 5: This graph shows the five column points that lie in the Euler region plotted so that the slope will be ($K\pi^2E$). Note that the line does not quite intercept the origin.

and we see that the maximum for these few points with the line drawn as shown is a deviation in log (P/A) of from 3.60 to about 3.63 or from 3980 psi to 4270 psi which is an uncertainty of about 300 psi. Question (g) cannot be answered by this presentation. Thus the "traditional" plot answers only two of seven questions and those poorly, while the log-plot answers five of seven questions and with considerable assurance.

The remaining questions can be examined using a plot of P/A versus $(L/R)^{-2}$ as shown in Figure 5. The slope of this line is, from Equation 1, (π^2 E K.) Since E is 10 x 10^6 psi for aluminum, we obtain a value of 1.68 for K after noting that the slope of this line is 160 x 10^6 psi. In this test, the columns were supported on ball-ended support so that the K value should theoretically be unity. This higher value is undoubtedly due to friction between the supports and the testing machine heads, which adds some stability to the column support system. Question (g) is answered in the negative as the line through these five points does not quite strike the origin. While this fact could be simply due to insufficient data, it should make us suspicious of our data and should suggest that more points might be taken.

This simple experiment has been extensively discussed for two reasons. First, it is common to the experience of most engineers. Secondly, it demonstrates how inadequately prepared most young engineers are for imaginative experimentation. If such a rich vein of inference and discovery lies untouched by junior and senior technological students, how much vaster is the area ignored by these same graduates in the crucial test work about which modern engineering revolves? And remember that we are discussing here only simple graphical methods. Statistical and mathematical tools receive even less experimental emphasis in our colleges.

THE CALIBRATION OF A WEIR FLOWMETER

Although few engineers use weirs in practice, they all calibrate one in undergraduate laboratory. A weir experiment is often the first test in which logarithmic plotting is required, since the equation for a V-notch weir

$$Q = K\ (\Delta H)^x \quad \ldots\ldots\ldots\ldots (2)$$

is assumed to apply (with Q as the flow rate, ΔH as the "head on the weir" and K and x as fitting constants). Figure 6 shows a typical plot of Q versus ΔH on logarithmic coordinates for two different sets of data taken by observers A and B. Since the weir and associated instrumentation were not changed between these two tests, we are interested in deciding which (if either) of these data-sets is correct. From Figure 6 we can obtain the approximate value of the exponent, x, in Equation 2 as 2.2. Then a plot of Q versus $\Delta H^{2.2}$ should show whether the A or the B set is more consistent, for we know that in any weir, flow and head should approach zero together. Figure 7 shows such an extrapolation check of the first kind and, although there is a suggestion here that B gives the more reasonable line, the large data scatter in both sets

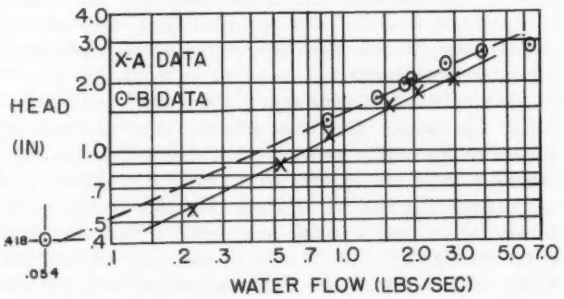
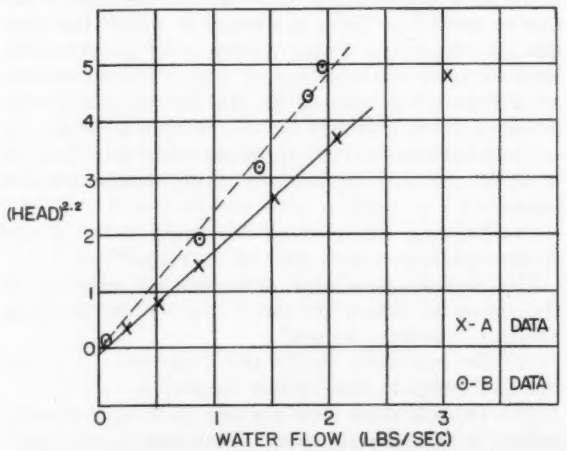


Figure 6: A typical logarithmic plot of two sets of weir data taken on the same apparatus.



Fgure 7: The weir data from Figure 6 are replotted here for an extrapolation check of the first kind. Because of data scatter, the extrapolations are of dubious use as a means of checking.

makes the check of questionable value. Since the two lines are rapidly diverging as flow increases, we might next think of an extrapolation check of the second kind, as shown in Figure 8. We assume that such a check will show the "good" data extrapolating to the origin since flow and head should reach infinity together. But Figure 8 reveals the unsuspected truth, namely, that neither A or B data is much good. Both sets extrapolate to a $(\Delta H)^{-2.2}$ value of about .04 as 1/Q reaches zero. Thus our data predicts that when the head on the weir reaches a value of 5.7 inches, the flow will be infinite!

This odd result is easily explained. The hook gauge used to indicate the location of the water surface was located so close to the outfall of the weir that it read head with progressively greater error as flow (and surface curvature) increased. Figure 9 shows the system diagramatically. Further investigation also showed that the A data was also wrong

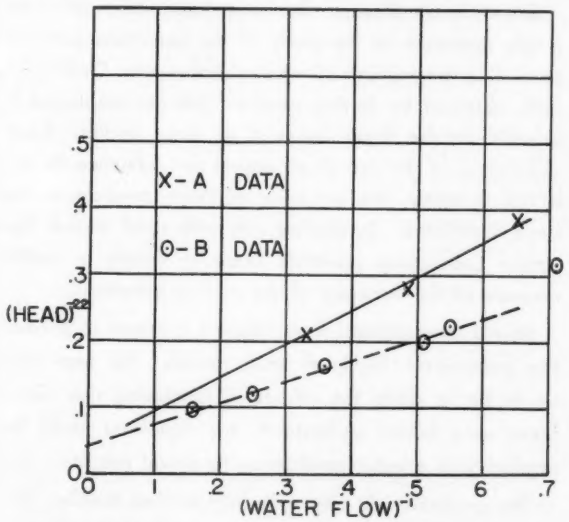


Figure 8: The weir data are replotted to permit an extrapolation check of the second kind. Neither curve extrapolates to the origin as consistent data should.

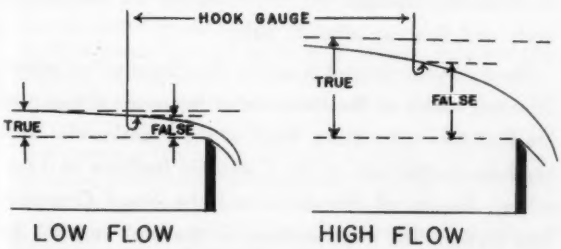


Figure 9: A cross-sectional diagram of the weir apparatus showing the reason for the failure of data to pass the extrapolation check. As the flow increases, the difference between the true head and the head read by the hook gauge gets progressively larger due to the curvature of the water surface near the outfall.

due to a faulty zero-head reading, as suggested in Figure 7. Thus may the tracking down of one obvious error reveal another and more serious defect in a test.

DISCUSSION

The use of graphical analysis in the checking of test data is rapid and revealing, yet seldom used properly. The simple methods outlined here, when applied to equally simple tests, can uncover great areas of unsuspected information. The industrial test engineer with professional pride of craft should never be satisfied with his data until he has exhausted the possible graphic interpretations. We can only guess at the amount of experimental inference that lies undiscovered because of failure to follow this simple rule.

The fault for this situation lies clearly with the college and university and the completely inadequate laboratory preparation given engineering and scientific undergraduates. We are still stressing test codes and archaic hardware instead of tough analysis and imaginative deduction. Expensive, yet understaffed, the student laboratory may well be worse than nothing as it is now taught. When we allow a student to present his column data in the form of Figure 3, we damage him in an educational sense. He may never again use a stability formula in his professional capacity, but he will certainly use graphs. The chance that he will use them sloppily and with little imagination is only too certain. We would do far better to forget *laboratory work* entirely and spend more time on the principles of *test analysis*.

There is no dearth of persons who can read numbers from a dial and copy them onto a graph sheet. But can we ever have enough engineers who see beyond the dial, the numbers, and the curve, to experimental truth?

REFERENCES

1. Schenck, H. "Correlations Relating Heat Transfer and Pressure Drop in Compact Heat Exchangers" *J. Am. Soc. Naval Eng.*, Nov. 1957, 767-770.
2. Schenck, H. "Heat Transfer Engineering", Prentice Hall Inc. (Englewood Cliffs, N.J.) 1959, Chapter 11.
3. Shoop, C. and Tuve, G., "Mechanical Engineering Practice" (4th Ed.) McGraw Hill Book Co. (New York) 1949, pp 396-397.
4. Mackey, C. "Graphical Solutions", (2nd Ed.) John Wiley and Sons, Inc. (New York) 1947, Chapts. V and VI.
5. Worthing, A. and Geffner, J. "Treatment of Experimental Data", John Wiley and Sons, Inc. (New York), 1943, Chapts. 2 and 3.
6. Doolittle, J. "Mechanical Engineering Laboratory", McGraw Hill Book Co., (New York) 1957.
7. Moore, M., "Theory and Application of Mechanical Engineering Measurements", D. Van Nostrand Co., Inc. (Princeton, N.J.) 1960.
8. Acton F. "Analysis of Straight-Line Data", John Wiley and Sons, Inc. (New York) 1959.
9. Liddicoat, R. and Potts, P., "Laboratory Manual of Materials Testing" The Macmillan Co., (New York), 1952, pp 96-97.

·J·J·HENRY·CO·INC·
·NAVAL ARCHITECTS · MARINE ENGINEERS · MARINE SURVEYORS ·

New York
21 West Street
New York 6, N. Y.
WHitehall 3-2870

Philadelphia
401 North Broad Street
Philadelphia, Pa.
WAlnut 5-1755

Cable: Henrycoinc

GIBBS & COX, INC.

NAVAL ARCHITECTS

AND

MARINE ENGINEERS

NEW YORK

H. NEWTON WHITTELSEY Inc.

NAVAL ARCHITECTS **MARINE ENGINEERS**

17 BATTERY PLACE, NEW YORK 4, N. Y.

WHitehall 3-6280 **Cable: WHITSHIP**

NAVAL ARCHITECTS
MARINE ENGINEERS

M. ROSENBLATT & SON, Inc.

NEW YORK CITY
350 BROADWAY
BEekman 3-7430

SAN FRANCISCO
216 MARKET ST.
EXbrook 7-3596

A $44,800 contract to determine how accurately the flight of an underwater missile can be predicted has been awarded to Stevens Institute of Technology by the U. S. Bureau of Naval Weapons, it was announced today (Wednesday, October 19) by Vice Admiral Howard E. Orem, Stevens Director of Research.

Scientists at Stevens' Davidson Laboratory will take a new approach to the study of the equations used for predicting the motions of missiles underwater. Ordinarily, data obtained by testing small models are employed in establishing the flight behavior of large bodies. Since differences in the size of an object can influence its behavior in water, the accuracy of these predictions has been questioned. By dealing only with small models Davidson Laboratory scientists hope to obtain a better measure of the accuracy of the motion equations.

Should they succeed in developing a theory to predict the underwater flight of small models, the next step would be to study the effects of increasing size. Once these were better understood, the equations could be applied with greater confidence to actual missiles.

The project deals only with fully wetted missiles, i.e., those completely surrounded by water. Under certain conditions the water around parts of a moving underwater body becomes gaseous. Known as cavitation, this phenomenon changes the forces acting on the moving body and thus can alter its path.

The two-year project is under the direction of Albert Strumpf, Head of the Underwater Weapons Division of the Davidson Laboratory. Most of the experimental work has been performed at the California Institute of Technology, Bureau of Standards and the Naval Ordnance Test Station. The main portions of Stevens' work will be analytical though some additional model experiments may be conducted there. Assisting Mr. Strumpf will be Howard Dugoff, Associate Research Engineer and Paul Knapp, Research Assistant.

Stevens Institute Press Release

"MARINE ENGINEERING/LOG"

CAN DESIGN ELIMINATE FOREBODY DAMAGE?

ACKNOWLEDGMENT

This article is a condensation of a paper by H. S. Townsend, "Some Observations on the Shape of Ship Forebodies with Relation to Heavy Weather," which was presented at the April 26, 1960 meeting of the New York Section of Society of Naval Architects and Marine Engineers. The condensation appeared in the May, 1960 issue of Marine Engineering/Log and is reprinted therefrom.

ONE OF THE BASIC requirements of all maritime interests is that a vessel maintain as much speed as possible under adverse sea conditions without resultant damage to the vessel, particularly the forward bottom.

While the foregoing is universal with respect to hull form, the approach to the method of accomplishing it varies considerably.

In this paper are set forth data which indicate the incidence of damage to the forward bottom of vessels for various types of forebodies. Also included are some observations on the types, as well as some of the general thinking of those at home and abroad who have concerned themselves with the problems.

It is recognized that the after body of a vessel is influential, although to a lesser extent than the forebody, on the performance of a vessel in a seaway. However, only the forebody is considered herein. And only general cargo vessels which, normally cannot be heavily ballasted are considered.

Possibly the following five categories of forebody sections are approximate:

1. Extreme "V" Shape
2. Moderate "V" Shape
3. Moderate "U" Shape
4. Extreme "U" Shape
5. Bulbous Bow

Figure 1 certainly would be considered in the extreme "U"-shape category. The forward sections are practically vertical in the area of the design waterline. Also, there is a considerable reverse in the design waterline. Figure 1 is the body plan of the C2 type. It is also typical of the C1, C3, and C4-S-A1 types.

Figure 2 shows the forebody sections of a vessel which might be termed "V" shaped. It is to be noted that the forwardmost sections are sharp, transferring to a full, rounded shape at stations 3 and 4. Even though the forwardmost sections are "V" shaped, the forward ends of the design waterline and the lower waterlines are very hollow. Figure 2 is the body plan of the VC2 ("Victory") type. To some extent it is similar to the C1-M-AV1.

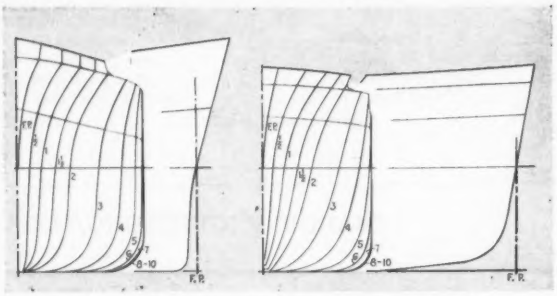


Figure 1 (left). EXTREME "U"-shaped forebody is typical of C1, C2, C3 and C4-S-A1 types.

Figure 2 (right). "V"-SHAPED forward sections are those of VC2 ("Victory") forebody.

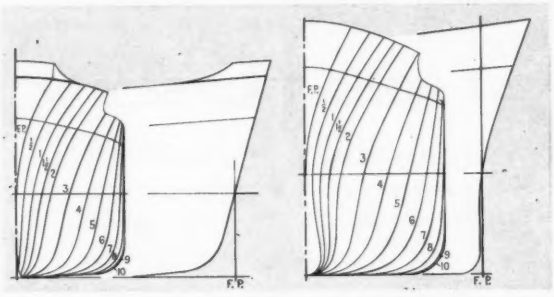


Figure 3 (left). MODERATE "V" compromise is from SNAME Resistance Sheet No. 69.

Figure 4 (right). MARINER-TYPE forward section shows moderate "V" with 4-per cent bulb.

Figure 3 shows the forward sections of a model of the moderate "V" compromise. This body plan is from sheet No. 69 of the SNAME Resistance Sheets. The model is included in this work for reference purposes.

Figure 4 shows the forward sections of the "Mariner" type which might be considered as illustrating the application of a 4-per cent bulb to an otherwise moderate "V" forebody.

INCIDENCE OF DAMAGE

Over a 26-month period embracing 10 months from August 1953 to June 1954, and 16 months from March 1958 to June 1959, a list of damages to the forward bottom of American-flag vessels, as compiled from the records of the United States Salvage Association, resulted in the data set forth in Table I.

Some points pertinent to the data in Table I are listed below:

The damages concern the setting in of the shell plating between internal members—often as much as 2 inches, and even more in a few isolated cases. In some instances the internal members were affected, and this is so noted in the table.

While the damaged areas are shown by strakes, and plates in those strakes, not all of any one plate is necessarily affected. In the over-all sense, this method of locating the damages is justified. In the more serious damages most such plates were damaged throughout, requiring renewal.

Where repairs were deferred, a careful estimate of the cost and time to carry out repairs was used.

No attempt was made to separate vessels of a type for which type there are only minor variations in construction of the forward bottom, shape, and/or dimensions.

Many vessels listed were repeatedly damaged, and often the repeated damage occurred within only a few months of the original repair.

The total cost of repairs for the 141 vessels affected was $3,084,905. The average repair time was 4.1 days. The foregoing costs represent only the cost of physical repairs and do not reflect cost of vessel during repair period, or loss of earnings.

Complete coverage of the load condition of the vessels listed in Table I, during the heavy weather when the damage was presumed to have occurred, was not available in every instance. However, enough data were available to indicate that the vessels were not all in the light condition, or actually slamming or pounding, when the damage was felt to have occurred.

There are no Liberty-type vessels included in Table I. The Liberty is decidedly of "V"-shaped sections forward and the type has a full (convex) design waterline. Additionally, the Liberty is of low power. Forward bottom construction follows Classification standards.

Most of the vessels listed in Table I were not specially stiffened above Classification requirements in way of the forward bottom, i.e., with extra shell thickness or auxiliary transverse floors or extra longitudinal members. In some instances during repair, when the bottom shell plating was removed, longitudinal flat bars, intercostal to the floors, were installed by owners. This extra stiffening of the shell has to some extent eliminated the setting up in way of the stiffeners, but has not entirely eliminated damage.

It is noteworthy that the mariner (C4-S-1A), with only minor extra stiffening above Classification requirements in the forward bottom, is not included in Table I as having suffered forward bottom damage.

The Mariner is fitted with five port and five starboard longitudinal girders in addition to the centerline vertical keel. These are outboard to a point approximately 13 feet off the centerline, specially located longitudinally on the forward bottom shell.

To draw the conclusion that bulbous bow vessels, per se, in view of the Mariner performance in serv-

TABLE I—*Incidence of Forward Bottom Damage American Flag Vessels 26-month Period*

Strakes & Plates Affected	Repair Cost (U. S. $)	Repair Time (Days)	Area of Heavy Weather
C1-M-AV1 Type			
K-2, 3 S-A2, 3 P-A2, B2	12,086	4	N. E. P. C'W
K-2, 3 S-A2, 3; B2 P-A2, 3; B2	21,995	5	N. E. P. C'W
Total: 7 Vessels	95,754	28	—
Av. Dam: 0.08L to 0.24L	**$ 13,679**	**4**	—
C1 Type			
K2, 3 S-A3 P-A3 6 Floors Disturbed	19,330	3	P E'D
K-2, 3, 4, 5 S-A3, 4, 5; B5 P-A3, 4, 5; B5	31,000	5	N. A. W'D
Total: 10 Vessels	246,679	50	—
Av. Dam: 0.09L to 0.21L	**$ 24,668**	**5**	—
C2 Type			
K-3 S-A3 P-A3	13,823	4	E. P. C'W
K-2, 3, 4, 5 S-A3, 4, 5; B3 P-A3, 4, 5; B3	41,846	6	W. A. C'W
K2, 3, 4 S-A2, 3 P-A2	22,890	4	N. A. E'd
Total: 58 Vessels	1,136,669	204	—
Av. Dam: 0.07L to 0.16L	**$ 19,598**	**3.5**	—
C3 Type			
K-4 S-A4, B5 P-A4	22,971	4	N. W. P. C'W
K-3, 4, 5 S-A3, 4, 5; B4; C4 P-A3, 4, 5; B1; C4	28,375	3	N. A. E'd
K-4, 5, 6 S-A3, 4; B4, 5, 6; C1 P-A4, 5; B5	35,610	4	N. A. W'D
Total 19 Vessels	404,417	73	—
Av. Dam: O.12L to 0.22L	**$ 21,285**	**3.8**	—
C4 Type (C4-S-A1)			
K-3, 4 S-A3, 4 P-A3	26,709	6	N. E. P. C'W
K-2, 3 S-A8, 9; B5, 6 P-A8, 9; B6	50,793	6	N. A. W'D
K-2, 3, 4 (Frs. 14-41) S-A4 P-A4	29,908	5	N. E. P. C'W
Total: 4 Vessels	133,612	21	—
Av. Dam: 0.10L to 0.20L	**$ 33,403**	**5.3**	—
Victory Type			
K-4, 5 S-A4, 5; B5 P-A4; B5	23,049	5	N. A. E'D
K-3, 4, 5, 6 S-A4, 5, 6; B1, 2, 3; C1, 2 P-A4, 5, 6; B1, 2, 3; C1, 2	57,400	11	N. P. E'd
K-3, 4, 5 S-A3, 4, 5 P-A3, 4	26,106	5	N. A. W'D
Total: 26 Vessels	645,251	129	—
Av. Dam: 0.11L to 0.23L	**$ 24,817**	**4.96**	—
P2 Type			
K-4 (Frs. 37-38) S-A4 (Frs. 37-39)	13,765	3	N. P. E'D
Total: 1 Vessel	13,765	3	—
Av. Dam: Centered 0.14L	**$ 13,765**	**3**	—
Special Type with Bulb			
K-4, 5 S-A4, 5 P-A3, 4, 5	24,090	5	N. A. W'D
K-3, 4 S-A3, 4, 5; B4, 5 P-A4, 5; B3, 4	40,127	7	N. A. W'D
K-3 S-A3, 4; B3 P-A3, 4	21,433	3	N. A. W'D
Total: 10 Vessels	248,288	41	—
Av. Dam: 0.12L to 0.24L	**$ 24,829**	**4.1**	—
Other Special Types			
K-3, 4 S-A3, 4 P-A3, 4	16,656	3	N. A. W'D
K-2, 3, 4 S-A2, 3; B3, 4 P-A1, 2, 3; B4	47,682	5	N. P. W'D
Total: 6 Vessels	160,470	32	—
Av. Dam: 0.10L to 0.18L	**$ 26,745**	**5.3**	—
Grand Total			
141 Vessels	3,084,905	581	
Average Per Vessel	**$ 21,879**	**4.1**	

Note: The above are representative excerpts from the original table.

Symbols & Abbreviations

Column 1

K = Keel
S = Starboard
P = Port
A = A Strake
B = B Strake
C = C Strake
1, 2, 3, Etc. = Plate in Strake (numbered from forward except where noted)
Frs. = Frames
C. V. K. = Center Vertical Keel
L = Length Between Perpendiculars
Av. Dam. = Average Damage

Column 4

N = North
E = East
S = South
W = West
A = Atlantic Ocean
I = Indian Ocean
M = Mediterranean Sea
P = Pacific Ocean
E'D = Eastbound
W'D = Westbound
C'W = Coastwise

ice, do not suffer from forebody bottom damage, would be erroneous. In the case of the Mariner, an excellent, moderate "V" forebody has had a well designed bulb added to it to obtain what was felt to be maximum speed performance in still water. It is conceivable that the fact that the Mariner does not suffer forward bottom damage is in spite of the bulb, not because of it.

An excellent, stillwater, extreme "U" bow, with a bulb added, based on the record of the extreme "U"-bow vessels without bulb, and without an extensive amount of stiffening above Classification requirements installed in the forward bottom, could certainly be expected to suffer from forward bottom damage. This is definitely the fact with respect to a group of a special type listed in Table I. This type has a bulb of approximately 3 per cent with the sections aft of the bulb being considerably more "U" than the Mariner.

FOREIGN APPROACH

Numerous standard design types of American flag vessels, and even some of the individual designs, reflect a considerable departure from the approach of those abroad. It is obvious that the "U"-"V" compromise, raked stem and cut-away forefoot, which features are seldom incorporated in American-flag vessels, predominate in most of the foreign designs for practically all speed levels. It should be stressed that simply because the raked stem and cut-away forefoot are found on most foreign-flag vessels, this definitely does not place them in the extreme "V" category.

The fact that "U"-shaped forward bodies predominate in the American approach does not mean that those abroad were, or are, not aware of the value of "U"-shaped sections for good, stillwater performance. G. S. Baker, in England years ago, may well have started the "U"-bow trend with his model "56-C."

Pursuit of a form which would lend itself to seakindliness but which retains some of the excellent power characteristics of the "U"-shaped forebody has resulted in a mean between the "U"- and "V"-forms. It is very common abroad. Very satisfactory power characteristics are obtained with this form which practically equal that obtained with the extreme "U"-shaped forebody.

It is not intended to dwell on speed and power comparisons of the various distinct types of bows, particularly inasmuch as the afterbody has been restricted from coverage herein. It is necessary, however, to more than simply indicate that satisfactory power performance can be achieved using bows with more "V" worked into them. Accordingly, reference is made to the qualitative works of the Swedish State Shipbuilding Experimental Tank; H. F. Nordstrom, and A. Lindblad, and to quantitative results reported by G. Aertssen; which specifically cover speed and power for vessels of the moderate "U"-"V" approach,

Attention is also invited to the power curves of the moderate "U"-"V" types shown on sheets 6, 7, 14 and 69 (Figure 3) of the SNAME Resistance Data Sheets. The moderate "U" model on sheet 7 shows practically identical EHP to the extreme "U" bulbous bow model shown on sheet 23, while the displacement of the former, on a 400-ft basis, is approximately 500 tons greater.

While the bulbous bow can be found in the merchant fleets of most nations, generally speaking those abroad do not favor the bulb. They also do not favor extreme "U"-shaped forward sections and a plumb stem profile below the design waterline. This holds true for all speed ranges.

Insofar as forward bottom damage is concerned, certain foreign owners were contacted whose vessels all follow a similar aproach to forebody shape, i.e., modified "U"-"V" sections, raked stem, and cut-away forefoot. The purpose was to establish the incidence of damage to this type of vessel, and to obtain the owners' thinking with respect to the shape of forward sections as related to the behavior of vessels in a seaway, and with respect to forefoot stiffening.

In all, the service experience of over 300 merchant vessels, of all ranges of speeds, trading in all areas of the world, was reflected in the responses from abroad.

The owners indicated:

Forward bottom damage, while not eliminated, is nowadays a rarity. Two owners indicated that no forward bottom damage had been suffered in the past 20 years of worldwide operation.

The general avoidance of forward bottom damage is felt to be the real result of one or more of the following: a) Forebody shape; b) added structure in the forward bottom; c) careful handling.

Vessels patterned along the lines of Baker's model "56-C" proved vulnerable to forward bottom damage. Over the years "U"-shaped forebodies have shown bottom damages for all practical ranges of speed, i.e., from 10 knots up. The likelihood of damage increases as the forward bottom is flattened, and additional stiffening is required in way of such flats.

It is thoroughly understood that the "U"-shaped forebodies lend themselves to good, stillwater propulsive characteristics. However, practically equal characteristics have been achieved with more "V" worked into the forebody. It is quite definitely stressed that the "U"-shaped forebody is not used because of excessive, vertical bow movement and the propensity to pound.

At the higher speeds more than usual "V" can be worked into the forebody, even showing a speed advantage in stillwater. Higher sustained

sea speeds in boisterous seas are maintained with the "U"-"V" compromise.

As the result of a series of tests by one owner, the conclusion was reached that there was no technical or economical reason to use a bulbous bow below a speed/length ratio of .95 (19 knots for a 400-ft ship, 21 knots for a 500-ft ship). At intermediate and low drafts the bulb is so objectionable as a spray raiser, and as a resistance raiser, that it would not be considered at any speed/length ratio for a general cargo vessel.

"S"-shaped design waterlines are recommended for higher speeds, providing for a reasonably low, half angle of entrance, together with a modified "V"-shaped forebody to minimize pitching and to avoid pounding.

Many vessels, during construction, are extra-stiffened in way of the forward bottom by the reducing of the transverse frame spacing. Forward peak tank spacing (or less spacing) is maintained a certain percentage aft of the collision bulkhead. Heavier keel plating and bottom plating adjacent to the keel (say 2 mm beyond Classification requirements) is installed aft of the collision bulkhead for a distance of about 22.5 per cent L.

Some vessels, in addition to the foregoing, are extra-strengthened at building by the installation of extra longitudinals forward, including a duct keel, and the forward extension of longitudinal midships members. All longitudinals then at least extend to a point forward of the tangent line on the flat of the bottom or the deadrise plane. (It is noteworthy that extra stiffening, beyond Classification requirements, is not extensive.)

Further on the subject of forward bottom strength, it has been opined by J. S. Redshaw that quite properly the Classification Societies take the view that the reasonable limit of structural reinforcement has been reached, and that the builder should not persist with shapes likely to induce forces which can be resisted only by special framing.

This thought would appear to have much merit. For indeed, until greater understanding is achieved of the dynamic forces (pressures) on the forward bottom of vessels in a seaway, the Classification Societies can hardly be expected to alter existing tabular scantlings to prevent damage.

Figures 5 and 6 illustrate the forebody sections typical of the type operated from abroad by those contacted.

The forebody prismatic coefficient of the vessel shown in Figure 5 is .654. The forebody vertical prismatic coefficient is .892. This vessel is powered by a 10,000-hp Diesel and is conservatively reported as operating, loaded, at a speed of 17.5 knots. The total deadweight at summer draft is 10,300 English tons. The design waterline shows a considerable reverse with a low half angle of entry (9½ degrees). The hull gives every indication of a form lending itself readily to being "pushed" to a higher speed range without undue increase in power.

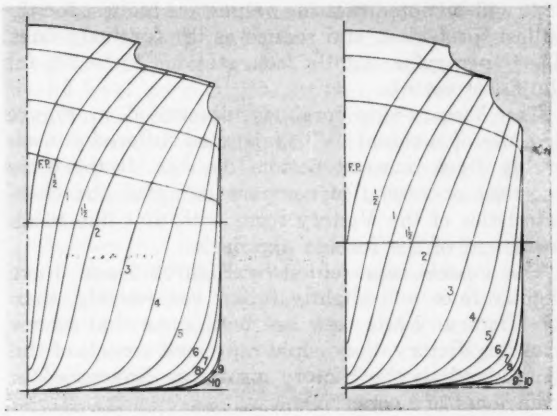


Figure 5 (left). MODERATE "U"-"V" type forebody, used abroad, can be pushed to high speed.

Figure 6 (left). ANOTHER moderate "U"-"V" type reported to be exceptionally sea kindly.

The forebody prismatic coefficient of the vessel shown in Figure 6 is .704. The forebody vertical prismatic coefficient is .882. This vessel is powered by a 7500-hp Diesel, and normally operates, loaded, at a speed of 16 knots. The total deadweight at summer draft is 13,145 English tons. The design waterline is straight from the entry to the beginning of the shoulder, and the half angle of entry is 18½ degrees. This hull is reflective of the fuller, middle speed type, which is considered exceptionally seakindly.

Figure 7 illustrates a plot of the section coefficients (area of each section divided by the area of a rectangle of width equal to the beam of the section at the DWL, and height equal to the draft at the section) for a broad fullness range of vessels of the moderate "U"—"V" type, with raked stem and cutaway forefoot, which are reported as being quite free from forward bottom damage.

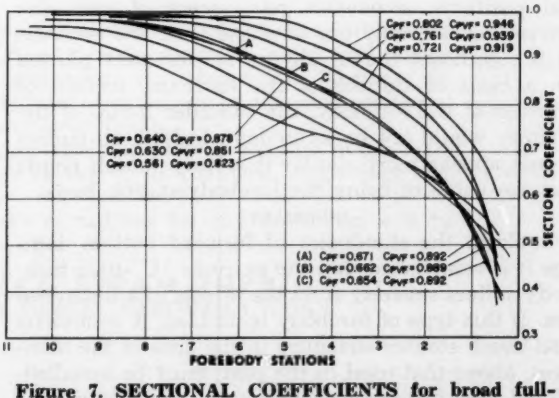

Cpv = 0.802 Cpvf = 0.946
Cpv = 0.761 Cpvf = 0.939
Cpv = 0.721 Cpvf = 0.919
Cpv = 0.640 Cpvf = 0.878
Cpv = 0.630 Cpvf = 0.861
Cpv = 0.561 Cpvf = 0.823
(A) Cpv = 0.671 Cpvf = 0.892
(B) Cpv = 0.662 Cpvf = 0.889
(C) Cpv = 0.654 Cpvf = 0.892
SECTION COEFFICIENT
FOREBODY STATIONS

Figure 7. SECTIONAL COEFFICIENTS for broad fullness range of vessels of moderate "U"-"V" type. Vessels of this type reported to be quite free from forebody damage.

It will be noted that the values are highest for the fullest forebodies, and reduce as the forebody fines. They then raise slightly from stations ½ to 2½ for the finest vessels.

The Victory-ship forebody illustrated in Figure 2, while of nominal "V" shape, has suffered considerably from forward bottom damage. It therefore becomes necessary to compare in detail the characteristics of the Victory form with that like block coefficient of the foreign approach.

The vessels represented by Figures 5 and 6 are slightly finer and slightly fuller, respectively, than the Victory. While they are both somewhat longer than the Victory, they could represent vessels of the same length as the Victory insofar as dimensionless coefficients are concerned.

It is noteworthy that vessels with sections exemplified by Figures 5 and 6, of nominally the same length as the Victory, are reported to be quite free from bottom damage (although some were slightly extra-stiffened in way of the forward bottom), and were reported as sea-kindly vessels. In view of the foregoing, it would appear worthwhile to compare the disposition of shape of the Victory hull versus the hulls illustrated in Figures 5 and 6. In Figure 8 the section coefficients have been plotted for these three hulls, at not only the design waterline, but also at a light draft of 0.4 and 0.7 of design draft at the forward perpendicular and after perpendicular, respectively.

An analysis of Figure 8 shows that the short entrance of the Victory produces a hard curve, loaded and light, at stations 5, 6 and 7. The slope of the curve from station 3, aft, is much steeper, light and loaded, than for the other two hulls. The transition in fullness is accomplished in a shorter length, and the whole transition is much further forward.

The average bottom damage of the Victory type is between stations 2 and 4. It is conceivable that there is a build-up of pressure ahead of station 4 due to the rapid filling out of the hull.

A further inspection of the curves shows the "humps" of the two types are at different longitudinal positions, somewhat reminiscent of two sine curves considerably out of phase with one another. It is significant that if all the curves were plotted on a basis of stations of the entrance, instead of stations of the forebody, the shoulder hump of the Victory would not be as evident. Indeed, all curves would appear more similar in nature, which points out the value of using the forebody-station basis.

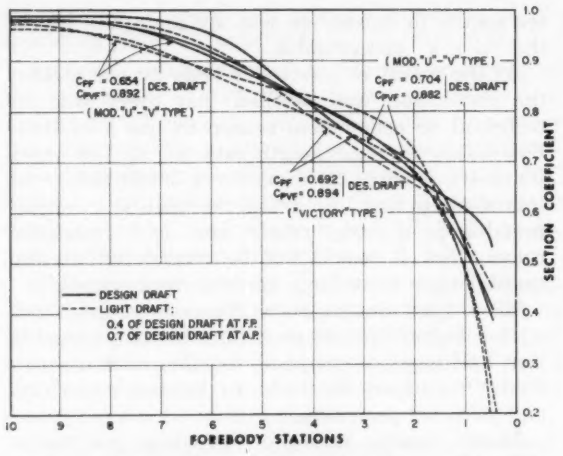


Figure 8. SECTIONAL COEFFICIENTS comparing Victory bulb with two moderate "U"-"V" types shown in figures 5 and 6.

SUMMARY

1. From the standpoint of forward bottom damage it is established that the extreme "U"-type forebody suffers severely from the effects of a disturbed sea. If this type of forebody is utilized, it is obvious that much stouter structure in the area of the damages, above that used in the past, must be installed. Model and full-scale experiments, and theory, indicate that with the use of extreme "U"-shapes, the greatest vertical bow amplitudes, for the broadest range of sea types encountered, are produced.

2. Experiments have shown a marked difference in the distribution of pressures on the forward bottom of the "U"-type versus the extreme "V"-type. Tests further strongly indicate that the sea speed that can be maintained in the broadest range of wave configurations, before too erratic a behavior obtains, varies with the amount of slope worked into the sides of the sections. The bulbous bow type also shows every indication of requiring ample side slope worked into the sections aft of the bulb transition sections.

3. It is reported by operators of the more moderate "U"-"V" types, practically exclusively used abroad, that forward bottom damage is a rarity, and further, that these types are regarded as sea-kindly. The difference in structure, if any, in the foreign types considered, versus that found in the extreme "U"-types which are severely damaged, is slight. This gives every indication that form plays a major part in the structural performance of a vessel.

4. Structural classification bodies are in no position to alter tabular scantlings or proffer recommendations until a much greater understanding of bottom forces is reached.

RECOMMENDATIONS

Studies relative to vessel performance among waves must of course reflect variations in forebody shape. It is submitted that an agreement should be reached on the method of separating vessels by shape type, such that distinct categories are created. The structural and motion performance of each type can thus be bracketed and compared.

Standard data, such as the SNAME Resistance Sheets for smooth water performance, should either be expanded to embrace data relative to perform-

ance in rough water, or standard rough water forms should be promulgated. In either case, full data to establish shape categories should be provided.

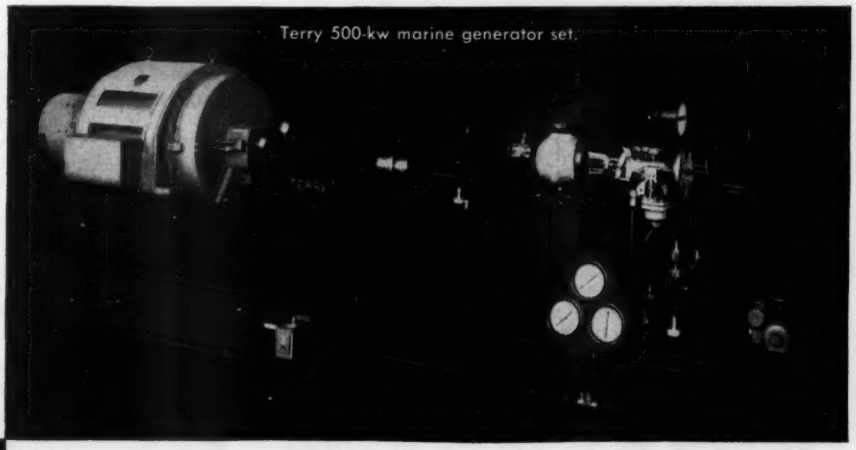
Vessel operators, repair yards, classification societies, and others in a position to accumulate heavy weather vessel performance or damage data all must work together in disseminating information to builders and designers, and to towing tank personnel particularly.

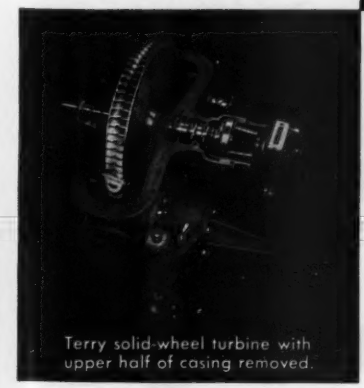
It is suggested that proper dissemination of factual data will not naturally come about. It must be brought about by the group which will profit most by it. If necessary, this work should be done on a professional (paid) basis, with the practical experience data gathered by the operators and provided to those the operators must look to for advice.

It is suggested that prior to the undertaking of involved and costly studies on the experimental and model level, serious thought be given to the collection of data relative to stillwater and heavy weather performance of existing, distinct shape types of vessels. These data should be analyzed with the intent of establishing the best over-all form which now exists.

The fact that the highest continuous service speed (approximately 20 knots) for scheduled general cargo vessels, on the Atlantic and the Pacific, is maintained by vessels of the moderate "V"-type forebody, without forward bottom damage, is a rather strong indication of where to begin.

Terry steam turbines


Terry 500-kw marine generator set.


Terry solid-wheel turbine with upper half of casing removed.

Dependable, compact, efficient . . . Terry marine turbines are specially designed for driving generators, boiler-feed pumps, fuel-oil pumps, compressors, etc., aboard ship. They are the result of over fifty years of experience in designing equipment for commercial and naval vessels.

Turbines ranging from 5 to 3000 hp are built in the Terry solid-wheel design as well as in axial-flow, single-stage and multi-stage types.

Complete details of turbines for any application will be gladly furnished.

THE TERRY STEAM TURBINE CO.
TERRY SQUARE, HARTFORD 1, CONN.

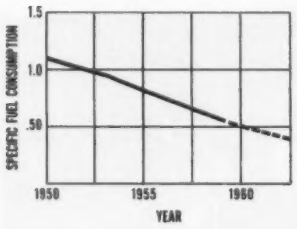
TT-1211

Small gas turbines soon to surpass piston engines for competitive applications

by Herbert Kunzel, President
Solar Aircraft Company
A Subsidiary of International Harvester Company

The gas turbine engine has made news this year as it has expanded into new and broader applications in the prime mover field. Behind this advance is continuing improvement in design and production. Even more advanced gas turbines will be developed in the next few years. In the small engine class (under 1000 hp) gas turbines will soon surpass overall piston engine performance and cost for competitive applications. They will also retain the inherent advantages of the gas turbine over the reciprocating engine.

One of the major reasons for this prediction is an impressive improvement in gas turbine economy. Previously, fuel consumption and high initial cost have kept the turbine out of all but selected power assignments. Industry and the military both thought the engines too expensive for most applications.



Through constant improvement, however, Solar has been steadily bringing simple cycle, small turbine specific fuel consumption down to an area competitive with piston engines. The fuel consumption of Solar's early 50 hp engines in 1948, for instance, was about 2.25 lb/hp-hr. The 1100 hp Saturn engine, which went into production this year, has the excellent simple-cycle fuel consumption of only .63 lb/hp-hr. Solar's experienced engineers improve life, "producibility," and performance characteristics with each new engine. At the same time, production costs are lowering rapidly.

Another significant advance in Solar turbine development has been the evolution of a unique design philosophy. Most gas turbines fall into one of two extreme categories: 1) Lightweight, high horsepower aircraft turbines, built to be as light as possible (about ¼ to ½ lb/hp), and 2) conventional industrial engines designed along the lines of steam turbines with a ratio of about 10 lb/hp. Both have inherent disadvantages. The aircraft turbines are relatively delicate with consequent problems of frequent overhaul and short life. Massive engine design, on the other hand, involves unnecessary bulk and difficulties with thermal lag and distortion. In either case, inherent advantages of the gas turbine engine are diminished and initial cost is adversely affected.

Solar's approach has been to develop a family of gas turbines that have both long life and light weight. The Saturn engine, with a weight-to-power ratio of 1.1 lb/hp, is heavier and more rugged than aircraft engines but much lighter than the usual industrial gas turbine. Although it is designed for long life, it has no more materials than are necessary to satisfy structural and thermal requirements.

Promising even further improvements in the turbine engine is the combination of Solar with International Harvester Company this year. IH saw the advantage of more power per pound several years ago. Their research and development has stressed performance and much work has been done by them on regenerative cycle turbines to reduce fuel consumption.

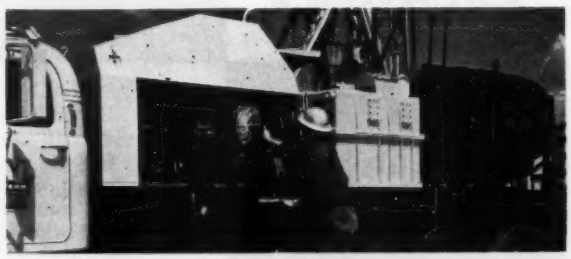
To basic research, they have added their many years of experience and leadership in high performance and low cost through efficient production of many thousands of IH engines for trucks, construction equipment and farm machinery.

Solar's successful Saturn engine development team and the combined research and resources of the two firms are now focused on further engine development in the area below 1100 hp. Preliminary design for a turbine in this range indicates that the following standards are feasible:

1. A life cycle equal to or better than conventional diesel engines—with considerably less maintenance.
2. Fuel consumption in the .4 to .5 lb/hp-hr range.
3. Cost competitive to conventional reciprocating engines.
4. Inherent ease of starting and operation in a wide variety of climatic conditions.
5. Small size and light weight.

Developments like these are certain to continue the increase in turbine applications and use.

For additional information write to Dept. H-303, Solar Aircraft Company, San Diego 12, California.



Saturn engine powering oil well fracturing unit

SOLAR
AIRCRAFT COMPANY
A subsidiary of International Harvester Company

GAS TURBINE PROPULSION FOR HYDROFOIL BOATS

ACKNOWLEDGMENT

This article is a condensation of a paper presented by Mr. Kenneth A. Austin of Lycoming Division, AVCO Corporation, at the last annual meeting of American Society of Mechanical Engineers. It appeared in the June, 1960 issue of "Mechanical Engineering" and is reprinted therefrom.

ALTHOUGH EARLY AIRCRAFT builders experimented with hydrofoil craft and the Wright brothers "flew" a hydrofoil boat at Dayton before they mastered the air at Kitty Hawk, the realization of their true worth has waited for improvements in structural efficiency, power plants, and hydrodynamics. These areas of research are closely related to aircraft practice, and indeed the performance of modern hydrofoil boats owes much to this well-endowed source.

The public concept of marine travel as that of quiet unobtrusive power is well satisfied by the natural smooth ride which the hydrofoil craft provide.

There is a parallel between aircraft and hydrofoil craft in the similarity of the natural critical conditions of sonic flight in air and completely cavitating operation in water. The respective changeover speeds for air and water are approximately 650 and 65 knots, a ratio of 10:1 for a density ratio of 800:1. For both mediums it can be proved that economical operation is possible beyond these speeds, but in such a case a consolidation of experience at high subcritical speeds is most desirable.

The main factor that allowed the efficient design of 100-ton Mach 0.9 aircraft was the use of the gas-turbine engine. As reported here, the same type of power plant has shown similar advantages in hydrofoil boats. It is clear that gas turbines offer a decisive breakthrough in hydrofoil vessel design, and that henceforth turbine-driven boats of 20 to 200 tons displacements can expect to offer new standards in speed, comfort, and economy.

POWER PLANT AND TRANSMISSION REQUIREMENTS

Although hydrofoil vehicles are almost as weight and power-conscious as aircraft, the power plant and transmission system have seldom been detailed in the literature. Since the merits of different foil systems are still the subject of vigorous debate, an engine manufacturer may be excused for being as neutral as possible.

The typical power and speed requirements for these craft are compared in Figure 1 with those for round-bilge and hard-chine boats. Once past the low-speed drag, which is higher up to the take-off

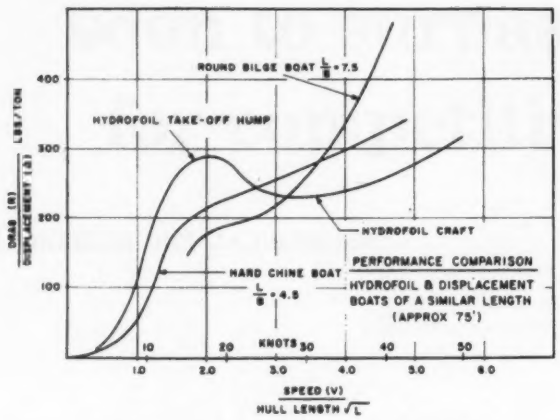


Figure 1. Power and speed requirements.

"hump," the speed achieved for a given power is much better than that for conventional boats. The take-off should be as short as possible to avoid wave pounding and should occur at a $V\sqrt{L}$ of less than 3.0. The power pattern, therefore, is one of short-duration maximum take-off power followed by a sustained 75 to 85 per cent power cruise. Low power is normally used solely for harbor maneuvering.

The examples of successfully demonstrated hydrofoil-craft propulsion arrangements [1, 2, and 5], are of two basic types; (*a*) Surface-piercing foils—where, for a given lift, the immersed area changes with speed; (*b*) fully submerged foils—where the immersed area is constant and a given lift is proportional to speed and foil incidence.

The layout varies considerably, with no distinctive trend evident for either foil system. As to propulsion through air or water, since this paper is deliberately limited to subcavitating craft with speeds up to 65 knots, the case for an air propeller is considered a minor item.

Air Propulsion

The normal use of directly coupled podded engines, avoiding the obvious complications of long underwater drives, and a specific transmission weight of about 0.30 lb per hp—less than half that of the simplest water-propeller system [3]—make air propulsion mechanically attractive. Below 50 knots, however, efficiency is normally less than for a water propeller. Although special high-activity propellers or compact ducted fans of 4.0 to 6.0-lb thrust per hp can be designed, the associated awkward above-decks arrangements and noise are undesirable. The public concept of marine travel is of quiet, unobtrusive power, and air propulsion, in the author's opinion, is bound to lose favor to a quieter mechanism. Relative difficulties are of no concern to a fare-paying passenger. He will support the most pleasant ride.

Water Propulsion

Power for subcavitating hydrofoil boats, Table I, calls for the installation of approximately 50 to 80-hp per ton displacement in as light and compact a package as possible, in a layout mainly influenced by the foil transmission system.

To date, the bulk of experience has been achieved on lightweight diesel engines of about 6.0 lb per hp bare specific weight. As at least 25 per cent more must be added for cooling equipment and other accessories, this means that the machinery weight has been between 18 and 30 per cent of the gross weight of the boat. Some experimental boats, such as the *Bras d'Or* [4] and the Grumman XCH-4 [7] have increased their performance by using the better specific weight of aircraft piston engines (about 2.5 lb per hp installed). By comparison, the machinery weight of a four-engine piston aircraft weighing 60 tons and carrying 75 passengers is about 8 tons or 13 per cent of the gross weight.

The percentage of boat weight on each foil varies according to the system used, but in general the center of gravity of the boat is normally about half the over-all length from the bow. This means that the larger, higher-powered boats have to use a central-engine-room arrangement, a less desirable location than toward the stern.

Air cooling of the engines is preferred because of the additional drag and annoying complications required to scoop up water when the boat is in the "flying" position.

Hydrofoil boats require the water propeller to be placed much further below the hull than is usual with a displacement boat, requiring a greater shaft angle, a longer prop shaft, or a bevel-gear drive mechanism.

The experimental LCVP *Halobetes,* Figures 2, 7, obviously called for a retractable foil and transmission system for beaching operations, but the modest draft of other craft and normal operation in navigable waters of good depth enable a fixed system to be used. The latter, however, has upper limits in the larger boat sizes. The added sea-state hull clearance required may mean that special-purpose boats and those above 100 tons will need a retractable transmission system [3].

The propeller must satisfy the conflicting demands of high thrust at low speed for a fast take-off and good efficiency when flying for an economical high cruising speed. Normal operation at high speed is usually the controlling factor and great care is taken to provide as clean an entry for the propeller-water inflow as possible. Long fixed systems such as the *Supramar* PT-10 and PT-20 use thin transmission shafts with a propeller mounted ahead of the final steady bearing to reduce interference to a minimum. Other boats such as *Halobetes, Bras d'Or,* and the *Flying DUKW,* Figure 3, that use gear drives have the propellers mounted

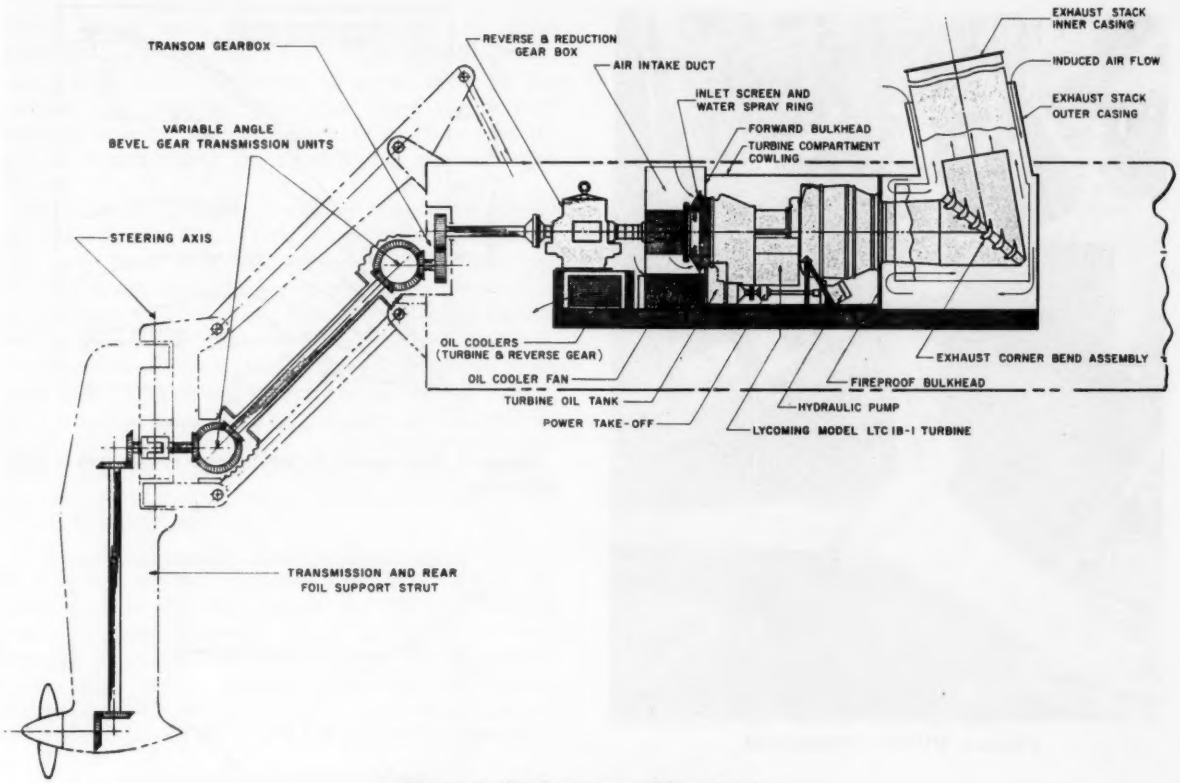


Figure 2. Halobetes propulsion system.

TABLE I—*Hydrofoil Craft—Design Specification Details*

Craft	Foil system	Designer	Length, ft	Displ. Δ, tons	V max. knots	Power, hp	Bhp Δ	Payload, tons	Payload, per cent
VS-6	Surface-piercing hoop	Shertel-Sachsenberg	50.0	17.0	47.0	1400	82.4	3.0	17.7
TS-6	Surface-piercing hoop	Shertel-Sachsenberg	39.3	6.3	40.0	380	60.2	1.4	22.2
VS-8	Surface-piercing hoop	Shertel-Sachsenberg	105.0	80.0	43.0	4000	50.0	26.0	32.5
PT-10	Surface-piercing hoop	Supramar	47.0	9.2	47.0	550	59.8	2.6	28.2
PT-20	Surface-piercing hoop	Supramar	68.0	28.0	43.0	1350	48.2	6.8	24.3
PT-50	Surface-piercing hoop	Supramar	88.6	50.0	43.0	2700	54.0	14.2	28.4
XCH-4	Surface-piercing ladder	Grumman	53.0	8.0	75.0	1260	157.0		
Sea Legs	Fully submerged incidence control	Gibbs & Cox	29.0	5.0	30.0	200	40.0		
Highpockets	Surface-piercing hoop	Baker	24.0	5.8	36.0	125	44.7		
Bras D'Or	Surface piercing ladder	Saunders-Roe	59.0	20.0	55.0	3000	150.0	3.5	17.5
Halobetes	Fully submerged incidence control	Miami S. C.	40.0	15.0	36.0	825	55.0	4.0	26.6
Flying DUKW	Fully submerged incidence control	Lycoming-Avco	32.0	13.0	27.0+	860	66.2		
Aquastroll	Fully submerged planing support	Aquavion	47.1	16.7	38.0	500	30.0	3.24	19.4

on slim, streamlined nacelles. The latter two use tractor propellers operating in undisturbed water to achieve the best efficiency.

There is a clear case for the use of a variable-pitch propeller in hydrofoil boats, particularly when bevel drive systems are used and the nacelle cross section provides sufficient area to mask the necessary hub diameter to accommodate the pitch-change mechanism. In addition to improving take-off and cruise performance, the variable-pitch propeller would eliminate the need and weight of an ahead and astern transmission.

TURBINE ADVANTAGES

Configuration

Free-power turbines or two-spool engines are the most suitable of various possible configurations. Single-shaft turbines are almost entirely limited to air-propeller-driven designs. The free-power turbine is simpler and better proved than the two-

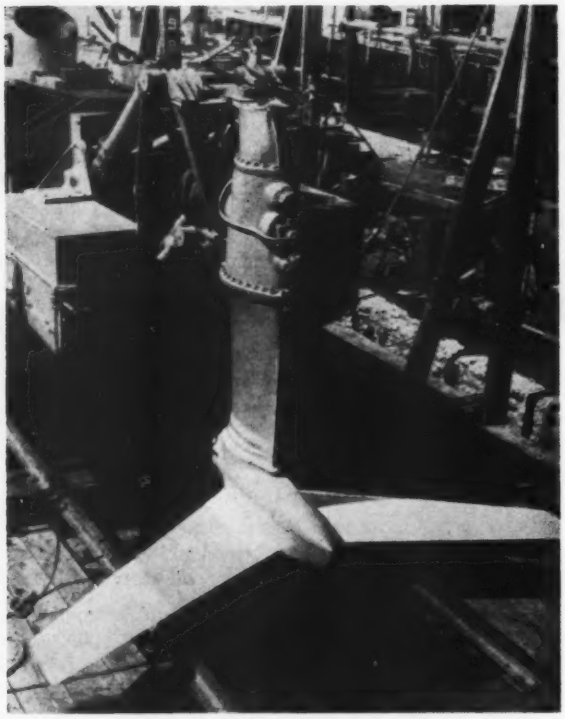


Figure 3. DUKW overstern unit.

spool engine, although the two-spool engine with the load connected to the l-p or h-p rotating units offers a higher pressure ratio and better fuel economy. Though in use in the newer aircraft and heavier industrial power plants, it has yet to be applied to surface transportation. It seems likely that it will become the basic design of the second generation of turbine engines for hydrofoil boats.

Power Characteristics

The point of maximum power for the free-power turbine, Figure 2, with respect to output speed, for an increasing range of gas-producer speeds is approximately an x^3 function. In other words, it closely matches the "prop-law" power requirement of a fixed-pitch propeller. If a variable-pitch propeller is considered, the fan of unique blade angle, power-absorption plots can be accommodated within the wide power spread.

Part-load fuel consumption of a turbine—that is, below 50 per cent load—is relatively unimportant with a hydrofoil boat since, as with an aircraft, over 90 per cent of boat operations are high-speed cruise at 70 to 85 per cent of maximum power.

With a free-power turbine, if the turbine is loaded up while maintaining the gas-producer speed constant, the output torque will rise and finally reach a fully stalled torque value of about twice that developed at maximum power. This characteristic, Figure 5, is markedly different from that of a piston engine and allows a high torque to be given to the propeller at low speed. The improvement in thrust gives a fast acceleration to the boat and a quick take-off, an effect that is valuable to a hydrofoil boat in rough seas.

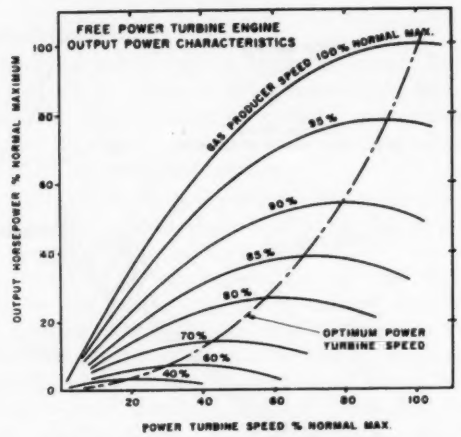


Figure 4. Free-power-turbine engine-output power characteristics.

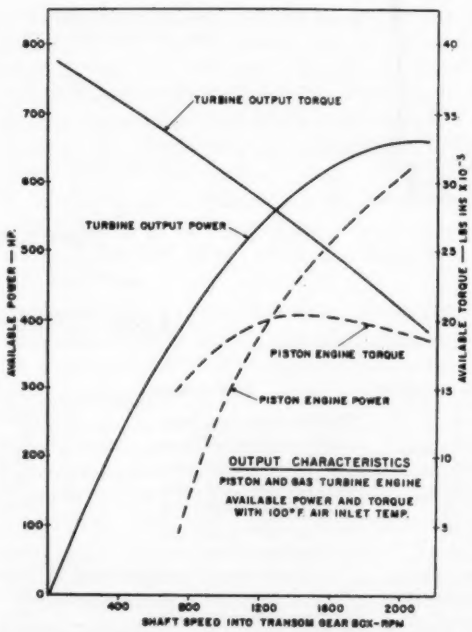

TURBINE OUTPUT TORQUE
TURBINE OUTPUT POWER
PISTON ENGINE TORQUE
PISTON ENGINE POWER
OUTPUT CHARACTERISTICS
PISTON AND GAS TURBINE ENGINE
AVAILABLE POWER AND TORQUE
WITH 100°F AIR INLET TEMP.
AVAILABLE POWER — HP.
AVAILABLE TORQUE — LBS INS X 10⁻³
SHAFT SPEED INTO TRANSOM GEAR BOX-RPM

Figure 5. Comparison of output power and torque characteristics of piston and gas turbine-engines.

Weight and Space

When comparing weight and power of current gas turbines and turbocharged diesel engines, the diesels are generally light-weight, high-speed ma-

chines. Many more different large turbines, above 2000 hp, have been built than large diesels. Development time and cost seem to be in favor of the turbine and increase with size. Even the robust, long-life marine turbines have many times better specific weights than the most highly turbocharged diesels.

Two further groups of engines should be briefly considered. Diesel-turbine compound engines can and have been built that are lower in weight per hp than heavy-duty turbines, but in the opinion of the author these engines, though creditable, represent extreme machinery design. They are costly to develop and deficient in reliability compared with what can be expected of present, let alone future, turbines. A type of gas turbine that should emerge in the near future will have an excellent maximum-power specific fuel consumption of about 0.40 lb per hp per hr, and will maintain this economy down into a low part-load range.

Turbines are smaller than the bare diesel engines by a factor of two or three, although air and exhaust ducting for the turbine can reduce some of this advantage. However, there is much less heat loss and less plumbing for a turbine. Turbocharged diesels need cooling equipment capable of removing 25.0 to 35.0 Btu per hp per min. A turbine requires cooling equipment for 1.0 to 3.0 Btu per hp per min.

HYDROFOIL CRAFT PERFORMANCE

An analysis of relative performance of a hydrofoil boat with turbines instead of piston power depends tremendously on the design chosen for comparison. One based on a series of boats using 60 hp per ton for a cruising speed of 50 knots is shown in Figure 6. It considers conservative turbine weights and turbine specific fuel consumptions ranging from 0.65 to 0.55 lb per hp per hr as the power requirement increased. No secondary weight-saving advantages in favor of the turbine were taken into account.

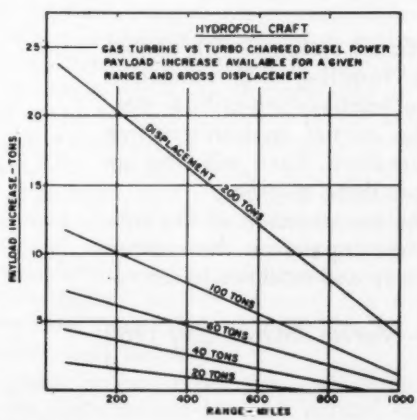


Figure 6. Payload increase made possible through turbine power.

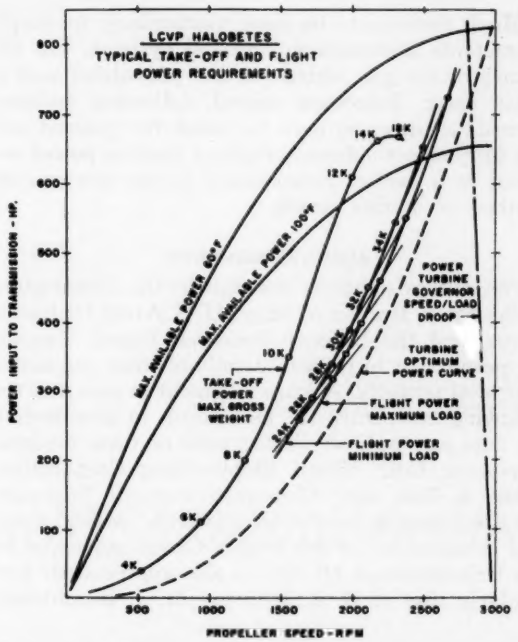


Figure 7. Halobetes power requirements. Once the craft had taken off and was past the "hump," power could be reduced 50 per cent and the boat still flew.

The plot shows large gains in payload for all displacements out to beyond a 600-mile range. Taking 250-mile range and existing hulls as an example, an average 30 per cent payload increase is shown to be obtainable with turbine power. The greater fuel cost is easily covered by the larger payload revenue or a lower operation "break-even" factor.

This analysis is conservative. It is based on current hull, foil-system, and engine design and does not reflect the further efficiency that could be obtained by maintaining the original payload and redesigning for a smaller boat and less power to carry it.

SUMMARY AND FUTURE PROSPECTS

Successful operation of hydrofoil craft, both as to economic commercial transportation and military advantage using boats similar to the 130-passenger *Supramar* PT 50, has been amply demonstrated. New commercial routes may be expected to open up, and larger and more sophisticated military craft will also appear.

The excellent performance of the lightweight diesel will be increasingly challenged by new generations of gas-turbine engines. For many designs, these are the only possible choices. In particular, the inherent propeller-power speed-matching characteristic of the free-power turbine has been demonstrated, together with the remarkable improvement that natural high-torque conversion of this engine can make to take-off distances and time.

Much remains to be done, particularly in simple retractable transmission and foil systems, but the future of the gas turbine as the propulsion unit is quite clear. Passenger appeal, following turbine-aircraft experience, may be taken for granted and the fully smooth characteristic of turbine power enjoyed as a perfect complement to the one smooth method of marine travel.

ACKNOWLEDGMENTS

The author's thanks are due to the Department of the Navy, Bureau of Ships, U. S. Army Ordnance Corps, and the Defence Research Board, Canada, for permission to publish details of their respective hydrofoil projects. Acknowledgment is also due the following companies for permission to give technical data and publish photographs of their designs: Supramar Ltd.; Miami Shipbuilding Corporation; Gibbs & Cox, Inc.; Grumman Aircraft Engineering Corporation; and Cabi-Cattaneo, Milan, Italy. The co-operation of the Design Group personnel on the *Halobetes* and *DUKW* is also appreciated; particularly that of R. J. Johnston, R. J. Hutchinson, and J. Buhler of the Miami Shipbuilding Corporation, and W. O'Connor, L. S. Votre, and G. Billings of Lycoming Division, Avco Corporation.

REFERENCES

1. K. Buller, "Hydrofoil Boats," 1952 Year Book—Schiffbautechnische Gesellschaft, Hamburg, West Germany.
2. H. Von Shertel, "Hydrofoil Boats as a New Means of Transportation," Lecture to the Society of Naval Architects and Marine Engineers, October 30, 1958.
3. L. A. Geyer and G. J. Wennagel, "Study of Hydrofoil Seacraft," Maritime Administration, October, 1958. Summary, U. S. Department of Commerce, November, 1958.
4. P. R. Crewe, "The Hydrofoil Boat—Its History and Future Prospects," Institution of Naval Architects, London, England, October, 1958.
5. T. M. Buermann, P. Lechy, J. J. Stilwell, "An Appraisal of Hydrofoil-Supported Craft," Society of Naval Architects and Marine Engineers, 1953.
6. K. A. Austin, "The Industrial and Marine Applications of Lycoming Gas Turbines," ASME Paper No. 57—F-38.
7. R. E. Apple, "Riding High—The Hydrofoil Story," *Research Review*, U. S. Office of Naval Research, March, 1956.

SUB MISSILE TENDER

Lengthened 44 feet to become the first Polaris submarine tender, the ***USS Proteus***, 17,000 tons displacement, now 573 feet long, is a complete seagoing repair shop for the missile-like guidance-navigation system of the Polaris submarines. The system uses large-scale computers and inertial navigation systems that sense and measure movement, each double-checking the other in order to compile and maintain the accuracy necessary to launch ballistic missiles underseas.

A 34 x 20-ft. repair center on the after port side of the main deck of the ***Proteus*** has been designed to handle navigational repairs and replacement at sea. A storage compartment several decks below inventories spare parts.

The repair center houses a working navigational system—with almost all of the instruments used in the submarine, together with simulation equipment, test panels, and ovens to store the temperature-critical inertial elements. Each oven holds 16 to 18 of the inertial, motion-sensitive elements, keeping them to a constant temperature. Each will ring an alarm on the bridge if the temperature changes three degrees.

An estimated 20 technicians will work on the maintenance of the submarine navigation systems. The tender will make repairs on the submarine's ship navigation system by exchanging parts and modules to be reworked in the repair center.

—Marine Journal, July 1960

DONALD L. HERR
Hon. Mem., Am. So. Nav. Engrs.

MODERN MODELS AND MODEL-MAKING

THE AUTHOR

has written many articles, several of which have been printed in the JOURNAL. *In 1945 he won the Society's prize essay contest by which he became one of the very few ever to attain Honorary Membership by this means. Mr. Herr has won many other honors. He is presently President of his own firm of Mark Instrument Co., Inc., Santa Monica, California.*

MANY EXAMPLES are recited of Faraday's use of his ingenious and purposeful mental constructs, or "models," in "explaining," understanding and extending the useful knowledge of his day and since, concerning particles, fields and forces.

Pre-eminently, a model of something ("the original," "the prototype") is characterized by an ordered likeness (one-to-one-correspondence) over each of one or more of the totality of ordered attributes definitive of the original or prototype. Likeness in some attributes characterizes a "partial" model of the original. Likeness in all attributes is, at least, "equivalence." Undifferentiability in all attributes is "identity." Non-singular transformations of an equivalent or an identity generate equivalents; some known, very useful examples are the "dual" and the "inverse" models. Singular, non-zero transformations of an equivalent or an identity generate partial models. Hence, the model sequence from the original or prototype is: identity, equivalence, partial, null.

Originals or prototypes, from which models relate, are characterized by their nature, viz., physical, functional, mathematical. While an identity is of the same nature as the original, the equivalent or partial need not be, in whole or in part, and, in general, is not. Thus, a physical system, as original, may have as equivalent model a mathematical model or a physical model, or a mixture of mathematical partial model and physical partial model, by way of example.

The "probabilistic-cause-and-effect," or the "teleologically adaptive," behavior or performance of a physical system original may be elicited by purposeful exercise and careful instrumentation of the physical system original itself. To within some known degree of its non-equivalence, a mathematical model of a physical system original may be exercised to elicit (with care, judgment and insight) the behavior or performance, and understanding, of the physical system original. In a circular feed-back sense, the physical system original, itself, may be exercised purposefully to help complete the valid and extensible mathematical model, and the understanding thereof of *both* the physical system and its mathematical model. The value-measure of a model derives from (1) its domain of valid and understood representation of the prototype, (2) its capacity to predict the behavior or performance of the prototype, (3) its valid, direct modification and extensibility to the perturbed proto-

type, and, (4) the degree of definiteness with which it clearly ceases to be a useful or valid model of the prototype, perturbed or not.

There is a slight and slowly growing, organized understanding of the "optimability," to some critique, of such vitally useful, commonly occurring, physical and functional, multi-dimensional non-linear systems—which industry, government, society and nature encounter and function in, continually. Such understanding, as it grows, enables a business, a community, a nation, to more effectively cope with and understand and "manage" the several, complex, multi-variable, non-linear, boundary-valued, variational problems which modern human society faces, whether they be of a technological, military, political, economic, sociological, or mixed, nature. Maximum advance use of *all* a priori available *or* obtainable "situation-information" is mandatory, the more so, the greater the "value" of the understanding of the problem, its total statement, and its non-optimum or optimum solution.

Three examples, among many, of potentially great civilian, industrial, economic and military usefulness and purposeful expenditure and savings of resources, are cited:

A. Time-mass, trajectory, guidance-control optimization;

B. Large-business and government "plant-and-process" control;

C. Ballistic tables (an inversion application of dynamic programming).

Typical of the modern model method and its learning-growth curve, deriving from "cross-ruffing" planned physical experiment, and consequent model improvements, is Example C. Here, a particular, shaped body, falling through the atmosphere-space, *solves*, in its trajectory of fall in the "Real World of Nature," the relevant multi-variable, boundary-value, non-linear variational problem. A basic mathematical model, computerized, may be used for *selective*, fine-grain construction of the sought-after, interpolated, multi-dimensional, "Ballistic" tabular arrays. Such a combination physical-plus-model program example uniquely resorts to but possibly 10-15 per cent of the total number of normally-required physical "drops" in the various modes, to develop such tables. It does so at great economy of time, money, equipment, facility and manpower. Most importantly, it does so at considerable increase of basic knowledge of a kind re-useable in future extension and applications, indeed, it discloses to the observant, unexpected extensions and applications.

Such modern model-making is more than a stimulating and satisfying exercise. It is—or can be—a challenging, many-cycled circular process of the utmost revelation, sophistication and humble self-checking. It increases our human *degree*-of-understanding, between the complex physical system, its intrinsic and extrinsic functional relationships, and its several partial or total models of mixed or homogeneous nature, disclosing progressively greater "validity," usefulness and Divine beauty. Faraday, that great and humble, alert and tranquil, soul and intellect, was blessed with such creative insight. He was, in fact, our first significant modern model-maker.

The first Polaris submarine trainer designed to simulate actual navigation, diving and missile firing has been "launched" by the U. S. Navy.

Now in the final stages of installation at the Submarine School, New London, Conn., the simulator was constructed for the U. S. Naval Training Device Center Port Washington, N. Y. It can be used to duplicate every aspect of a typical missile launch problem.

Technically integrated by General Dynamics Corporation's Electric Boat Division, the overall facility is expected to provide the Navy with a quicker and more efficient system for molding Silent Service personnel into highly-specialized FBM submarine teams.

The facility includes a Dynamics-designed diving unit and navigation trainer. The former can pitch and roll exactly as would its fleet counterpart and the navigation trainer is equipped with a synthetic sky and an electromechanical computing system that produces signals representing changes in latitude and longitude.

Slated for full operation in 1961, the facility will also be used for refresher training by crews now sailing the nation's first two Polaris subs.

—General Dynamics Corporation

COMMANDER BERNARD M. KASSELL, USN (RET)

MARINE ENGINEERING NOTES FROM THE SOVIET PRESS

THE AUTHOR

enlisted in the Navy in 1931, and has served continuously since that time. He attended Cornell University and Maryland University, obtaining his B.S. degree in Military Science from the latter institution. He has had a wide range of duty assignments, including tours as Engineer Officer and Repair Officer on various ships and tenders. He was recently stationed in Casablanca, Morocco as Commanding Officer, Military Sea Transport Service and retired recently after 29 years of active duty. His last duty station was in the Office of the Chief of Naval Operations. Is now engaged in consulting and independent research on Soviet affairs.

THE SOVIET MERCHANT MARINE

THE SOVIET MERCHANT MARINE, today, is larger in size—in numbers of ships and in total carrying capacity—than ever before in the history of either Czarist Russia or of the Communist regime. By the end of 1965 the total tonnage of this fleet is to be double what it was at the end of 1958. According to figures compiled by the U. S. Department of Commerce, at the end of 1958 the Soviet flag flew over 774 merchant ships of 2,789,000 GRT and 3,809,000 deadweight tons. These figures are for ships of 1,000 GRT and over. Soviet figures are, undoubtedly, all-inclusive, down to the smallest barge and tug. Never the less, based on 1959 deliveries and the following list of deliveries, or ships nearing completion and which could be delivered by the end of the year, the plan will, in all probability, be met.

The addition of such ships as the tanker *Pekin* (19,000 GRT), which can make the run from Odessa to Vladivostok in 20 days, and her sisters *Budapesht* (launched in June) and *Varshava* (launched in August), the turbine-drive cargo carrier *Leninskiy Komsomol* (12,016 GRT) and others of this class, along with ships imported from the captive nations and from Western building yards, will increase the total tonnage figures very quickly.

However, progress is not without its problems. Mr. N. Byikov, a member of the Collegium of the Ministry for the Maritime Fleet, pointed out, in September, that some of the *sovnarkhozes* (Councils for the National Economy, see the "Journal," May, 1959, p. 339) have failed to meet plans for the building of transportation equipment, including merchant ships. Certain of the plants acting as subcontractors failed, in 1959, to meet production quotas for sub-assemblies and articles needed in the building program. At the same time, unspecified shipyards actually failed to lay down nine ships scheduled for production, involving 70,000 tons of carrying capacity—eight in the Leningrad *Sovnarkhoz* area alone.

Ships under construction, according to Byikov,

are falling behind schedules. Leningrad area shipyards, in the first six months of 1960, met their combined building program by but 64 per cent, with the Admiralty Shipyard, builder of the atomic icebreaker *Lenin*, singled out as the worst offender with a half-year percentage figure of but 8 per cent! The yard, it seems, had not yet started construction of the new, port icebreaker class (see below), the first of which was scheduled for operation this year—and this despite the report, in May 1960, that the first of the class had actually been launched. Nor had construction begun on the gas-turbine propelled tanker which is supposed to be in service sometime in 1961. This is the 13,000-horsepower, twin turbine ship with a capacity of 17,000 tons and a speed of 17 knots.

The Baltic Shipyard, designated as a building yard for timber carriers, is cited for its slow rate of construction on *Mezenles* which, at the beginning of August was but 30 per cent completed, despite the fact that the schedule called for 60 per cent completion on that date. *Mezenles* was originally scheduled for completion in the fourth quarter of 1960.

Although *Varshava* was reported running trials in the Baltic in mid-August, and although other reports indicate that *Budapesht* is scheduled for completion some time this year, Byikov claims that both ships are lagging behind schedules.

The construction of *Kirgizstan*-class passenger ships is said to be unsatisfactory in the *imeni* A. A. Zhdanov Shipyard, Leningrad, where the builders were 28 per cent behind schedule at the end of August. Enterprises under the administration of the Kherson (Black Sea) and the Khabarovsk (Far East) *sovnarkhozes* have, for some months, failed to meet building programs. One citation is made. An unidentified hull, Number 806, scheduled for service in 1961, had, at the end of July, reached 22.6 per cent of completion, with the average monthly rate of production given as 3.2 percent.

All these shipyards are under the jurisdiction of the *sovnarkhozes* and, accordingly, are involved with the State Committee for Shipbuilding. This connection undoubtedly involves some use of building capacity for naval construction, to the obvious detriment of commercial building. However, as Byikov points out, shipyards directly subordinate to the Ministry for the Maritime Fleet are faring no better. Production figures for the first six months of 1960 for this group of shipyards were at 66 per cent of plan, with particularly poor results having been obtained from the Kiliya, Riga, Odessa, "Krasnaya Kuznitsa," and other shipyards.

Steamship company chiefs exercising direct control over shipyards in their respective areas were urged to tighten up control over ship building programs and bend every effort to getting unused production capacity into action. The Ministry itself was urged to press design organizations for timely receipt of plans for new tankers and for other transportation means so that review could be carried out and shipyard capacity set to work.

The following list of merchant ships delivered thus far in 1960, or under construction (marked with an *) and which will probably be delivered this same year, is not all-inclusive, but is indicative of the progress being made towards the 1965 goal.

Name	Where Built	Type	GRT
Agdam, m/v	USSR	Cotton-timber	3000
Aleksandrovsk, m/v	Finland	Cargo	5513
Aleksandr Terekhin, s/s	Poland	Cargo	3816
Almetyevsk, m/v	Finland	Cargo	5512
Andrey Zakharov	USSR	Crab cannery	
Aragvi, m/v	West Germany	Refrigerator	4410
***Armeniya**, m/v	East Germany	Passenger	4871
Atkarsk, m/v	Finland	Cargo	5411
Babushkin		Cargo	
Baku, m/v	USSR	Cotton-Timber	3000
***Bolshevik Karayev**, m/v	Bulgaria	Tanker	3000
***Budapesht**, s/s	USSR	Tanker	19500
Chelyabinsk, m/v	East Germany	Cargo	3359
Dalnyiy, m/v	Poland	Cargo	3359
Diomid, s/s	USSR	Salvage Tug	828
Dzhankoy	East Germany	Cargo	
Estoniya, m/v	East Germany	Passenger	4871
Firovo (renamed **Sena**)			
Fizik Vavilov, s/s	USSR	Cargo	12016
Goncharev, m/v	Poland	Fish Factory	2600
Goryachiy, m/v	Rumania	Tug	
Izhma, m/v	East Germany	Cargo	3359
Izyaslav, m/v	USSR	Tanker	8229
Kapitan Fedotov		Oceanographic	
Khorol, m/v	East Germany	Cargo	3359
Kirgizstan, m/v	USSR	Passenger	3219
Kokand		Survey	
Komiles, m/v	Poland	Cargo	4200
***Komsomolets Primorya**, m/v	Finland	Tanker	3300
Krasin, s/s[1]	USSR	Icebreaker	4902
***Kremenchug**, m/v	USSR	Tanker	8229
***Kura**, m/v	West Germany	Refrigerator	4410
***Labinsk**, m/v	Poland	Cargo	9935
***Latviya**, m/v	East Germany	Passenger	4871
Leninskiy Komsomol, m/v	USSR	Tanker	8229
***Leskov**	Poland	Fish Factory	
***Lesozavodsk**, m/v	Poland	Cargo	9935
***Litva**, m/v	East Germany	Passenger	4871
Mamin Sibiryak, m/v	USSR	Fish Factory	3170
Mariya Ulyanova, m/v	East Germany	Passenger	4720
Metallurg Baykov, s/s	USSR	Cargo	12016
***Mezenles**	USSR	Timber Carrier	
Moldaviya, m/v	USSR	Passenger	3219
Mongugay, m/v	East Germany	Cargo	3357
***Morekhod Kuskov**, s/s	Poland	Cargo	3812
Moskva, d/e	Finland	Icebreaker	9200
Neringa		Survey	
Neva, m/v	Denmark	Fish Factory	3321
Nikolay Isayenko, m/v	Japan	Fish Factory	4987

1. Originally built in England in 1917, has just been completely overhauled and remodernized. Now has one stack instead of two; deck installation and superstructure completely changed. Engine power has been increased.

Partizan Bonivur, m/v	Poland	Cargo	9935
***Pavlin Vinogradov**, m/v	USSR	Timber Carrier	
Pechenga, m/v	Poland	Trawler Tender	
Persey-II		Survey	
Petr Lebedev	USSR	Survey	
***Rovno**, m/v	USSR	Tanker	8229
Rudolf Blauman, m/v	USSR	Freezer-Trawler	3170
Sena, m/v (ex-Firovo)	Finland	Cargo	1870
Sergey Vavilov		Survey	
Sovetskaya Litva, s/s	Poland	Fish Factory	11540
***Sovetskaya Rossiya**, m/v	USSR	Whaler	32024
***Sumyi**, m/v	USSR	Tanker	8229
Svanetiya, m/v	USSR	Passenger	3219
Tiksi, m/v	Denmark	Cargo	9500
Turukhansk		Cargo	
***Ussuriysk**	USSR	Refrigerator	
Varshava, s/s	USSR	Tanker	19500
Vatslav Vorovskiy, m/v	East Germany	Passenger	4720
Volgoles, m/v	Poland	Cargo	4200
Volodya Dubinin, m/v[2]	Hungary	Training	1194
***Yelsk**, m/v	USSR	Tanker	8229
Yu. M. Skokalskiy, m/v	USSR	Survey	3600
Yuriy Dolgorukiy, m/v[3]	East Germany	Whaler	32024

2. Former cargo ship refitted as a training ship for the use of the Baku Maritime School on the Caspian Sea.
3. Ex-Hamburg, raised in 1952 and refitted as a whaler, assigned to the port of Kaliningrad and being readied, late in the summer, for Antarctic season.

THE FAR EAST

Shipping in the Soviet Far East has its own problems, not the least of which is weather. Most of the cargo movements take place during the 3rd quarter of the year (36.5 per cent), while 1st quarter movements are slackest (14.3 per cent). Cargo is of a varied nature, including industrial and food products, construction materials, timber, coal, salt and fish products, and military supplies and equipment. Cargo, in general, moves in one direction only.

Because of this combination of circumstances, the fleet of merchant ships in the basin, operating under the Far Eastern, Sakhalin, and Kamchatka steamship companies and the Far Eastern Fishing and Refrigerator Ship organization, must be made up of special types of ships. Actually, the types which have been provided as part of a broad program of augmentation and replacement are not exactly suitable for service under these conditions.

Operators complain that the ships which have been provided lack facilities for heating inner-bottom ballast and fuel tanks; that lack of adequate insulation in the living spaces results in damaging condensation; that anchor chain is of too small a size for the conditions which the ships encounter in open roadsteads; that cargo boom fittings for securing the booms in the vertical position when the ships are underway are inadequate; that faster acting, more reliable, and watertight hatches are needed.

Passenger ships should have at least two holds for carrying small shipments of urgent cargoes, one of which should have a refrigeration installation. This type of ship need not be large and the cabins should, in the main (80 per cent) be four-bunk ones, with the remainder divided among two-place and single cabins. Luxuries such as music salons, dance floors, bars, and separate dining rooms for individual classes need not be included.

A surprising deficiency has arisen in radar equipment. While deficiencies in the *Neptun* and *Stvor* radars are of long standing, it is now found that the more recent *Don* radar suffers from manufacturing faults and is relatively unreliable. The radio direction finder, Model "Srp-5" is a very reliable installation, but the loop is subject to cracking. All this equipment is of Soviet design and manufacture.

Most of the ships involved are of foreign construction, but most, if not all, have been, or are, built on plans provided or approved by Soviet engineers and naval architects. So it is surprising indeed to find Soviet operators complaining that they have ships operating on heavy fuels not readily available; that it is difficult to obtain spare parts for these foreign-built ships.

Recent conferences on the subject have resulted in operators making the following recommendations with regard to new ships assigned to the Far East:

(a) that tank heating systems be installed in all water ballast, fresh water and heavy fuel tanks;

(b) that insulation in living and working spaces protect against outside air temperatures as low as −20°F;

(c) that all steam and condensate piping running to bow machinery from the engine room be laid in a special tunnel to prevent freezing;

(d) that hull strength be improved to meet requirements for ice operations as defined in the Register of the USSR;

(e) that dust and moisture-collecting materials in compartments and living spaces be eliminated;

(f) that the use of the 3D100 and D50 engine types be eliminated in Far East ships because they have proven to be unreliable in conditions in the area;

(g) that facilities be installed to permit disembarkation of passengers in open roadsteads;

(h) that on-board means be provided for use in moving cargo from ship to shore in the Arctic.

It will remain to be seen if any of these recommendations are incorporated in the new ships which are to increase the volume of shipping in the Far East to a figure, at the end of 1965, 54 per cent greater than that available at the end of 1958. The addition of this volume of tonnage, probably on the order of a half million tons of capacity, will, it is planned, permit the fleet in the Far East to increase its cargo turnover to a figure 85.7 per cent greater than the 1958 figure. Too, by the end of 1965 it is planned that the use of this fleet in the export-import trade will reach 56 per cent of the total cargo turnover and will be 2.3 times that of 1958.

BRYANSK DIESEL WORKS

Bryansk, site of a machine-building works, has been designated to build a big, slow-speed diesel engine to be rated at 9000-horsepower. The organization of a diesel division was started, as was the manufacture of the individual parts for the engine, and 1960 was set as the target date for the delivery of the first of the engines, to be used in Soviet-built merchant ships. The deadline will, from all reports, not be met.

So serious was the problem that, at mid-year, a conference, attended by representatives of the works, the Central Scientific Research Institute for the Maritime Fleet, and other organizations, was called. The Bryansk Works director was told to build a test stand, as well as an experimental laboratory to conduct tests as needed. The Ministry for the Maritime Fleet was asked to conduct shipboard testing of parts and to provide technical assistance as needed by the works; a new twist to the US practise of having factory representatives sent to the ships.

Finally, the Ministry for Higher and Middle Special Education was asked to organize a Diesel Building Faculty in the Bryansk Institute for Transport Machine Building in order to train diesel engineers.

Let us take a little closer look at this problem, for, because of the great successes scored in the field of rocketry and in the use of missiles, we have tended to the view that such success extends across the board. Discrediting this view are the views of three Soviet engineers, V. Andreyev, F. Burmistrov and F. Kolpakov by name, employed in Bryansk.

This is their story. They work in the design bureau and have been assigned to the development of the sketch plans for a completely new model, slow-speed diesel for future use. Their deadline was the third quarter of this year. Yet they have not as yet been told what the horsepower of this engine is to be either in the near future or in the next 10 to 15 years. Their own decision was to draw plans for an engine which would develop 1500 horsepower per cylinder. Despite their best efforts, however, they have been unable to do all the work required because their bureau does not have the manpower. The laboratory recommended at the mid-year conference had not, by September, been installed and the only laboratory available, located in the experimental shop, cannot provide the support needed. It is too small, poorly equipped, both in instruments and test stands, and has few specialists.

Recalling that this is the very first enterprise in the Soviet Union to organize the production of big marine diesel engines, the engineers feel that it is no more than right that a branch of the Central Scientific-Research Diesel Institute or of the Central Scientific-Research Laboratory be formed in the works so that workers can be trained and the work done better and cheaper.

Bryansk is a big rail junction on the Moscow-Kiev Railroad and the Machine Building Works builds turbines, power trains, diesel locomotives and freight cars which are exported to all parts of the Soviet Union and abroad as well. Despite what would appear to be a considerable backlog of experience, the superimposition of diesel manufacturing seems to have caused a considerable disruption in production. Director Yushkov, Chief Engineer Gorbunov and Production Chief Zaytsev are all charged with failure to exercise needed control over the manufacture of parts needed for the new engine. The turbine shop, for example, scheduled to manufacture 5200 parts for the new engine, in six months managed to turn out 56 of the least complicated. This failure was reflected in lack of production from the foundries. In addition, cooperating, external plants failed to deliver machinery.

Grinders, products of the Kharkov Machine Tool Building Works, failed to arrive on pre-fixed dates; a Khabarovsk plant refused to make certain high pressure air delivery equipment; the Kramatorsk Works is manufacturing cylinder liner honing equipment; other plants, such as the *imeni* Ordzhonikidzye in Moscow, the Shchelkovskiy Pump, *imeni* Sedin in Krasnodar, the Uralsk Compressor, and others are similarly engaged. Without the production from these enterprises, the lubricators, starting air bottles, drive chains for cam shafts, etc., it is little wonder that troubles piled up.

But hopes are high, it seems, as the fond planners compare their infant with such established giants as the Sultzer, MAN, Doksford, Goteverken, and other diesel builders. The new engine is said to be reliable, easy to service and will not need big, unreliable reduction gearing. It will be turbo-supercharged and will operate on cheap grades of fuel. In a comparison with engines in *Dneproges* (4x 1800-hp) and *Groznyiy* (2x2000-hp), it is pointed out that these engines require an annual repair period of from 30 to 60 days, the cost of which ranges from 225,000 to 485,000 rubles. The cost of the spare parts alone is some 175,000 rubles. Capital repair is required every 4 to 6 years. The new engine, by way of contrast, will need but 7.5 days per year in repair and this work should not cost over 75,000 rubles, with spare parts cost set at 4,000 rubles. Capital repair will not be needed in under 16 years since the engine has an operating life of 80,000 hours.

FLOATING DRYDOCKS

Soviet planners have settled on the floating drydock as a major means for ensuring that repairs will be accomplished in timely fashion on the steadily increasing merchant fleet. Needless to say, repairs to naval vessels can be accomplished in the same docks. There is, however, an interesting reason for the choice, particularly in the Caspian Sea basin.

It is a well known fact that the water level in the

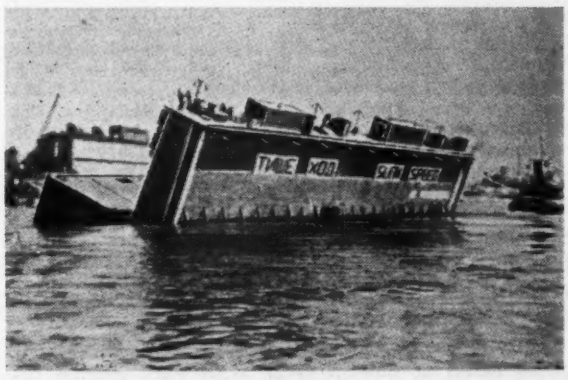
Caspian Sea has, for many years, been falling steadily. Recently, as a consequence of this drop in water level, certain fixed installations in the Baku area, including a drydock, have become useless since ships cannot be brought to the dock, or to marine railways, on the coastal area.

For the Caspian, then, the solution was the ordering from the Kherson Shipyard of a reinforced concrete dock, designated *K-1*, capable of lifting 6,000 tons. It is classified as an experimental unit. This dock, 465 feet along the floor and 72 feet wide (the outside dimension is 99 feet), is big enough to take any active ship on the Caspian, or any ship planned for use on the sea.

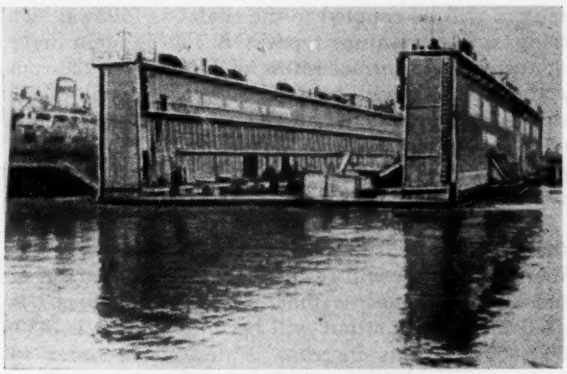
Since the dock was for use in Baku the transportation problem was a serious one. The 48-foot high side walls making up an installation weighing almost 10,700 tons, had to follow a devious route to destination—the Dnepr River, Black and Azov seas, the Don River, the Volga-Don Canal, the Volga River, and finally, the Caspian Sea. Conditions along this route are such that the tow could not be towed as a unit. In fact, one of the locks on the Volga-Don Canal is shorter than the overall length of the dock and the planned width of the dock is far in excess of the width of the locks. The solution was to build the dock in sections and, as finally built, was in four L-shaped pieces, each capable of withstanding the rigors of the tow across the Black and Azov seas.

The old system of using pontoons (see the "Journal," May 1960, p. 302) was resorted to once again with the use of steel pontoons assembled along the sides of the sections. Three pontoons along the length of the section permitted controlling the angle of heel needed to get the section over shallow spots on the rivers. Each pontoon was 7.7 feet wide and 13 feet high.

The first tow, from Kherson to the Ochakovskiy Water Gage Point was made on an even keel, but on the next leg, to Khdanov, the section was listed 17 to 20 degrees. From Zhdanov to Astrakhan the tow was again on an even keel. However, at one point on the Don it was necessary to flood the section and list it 42 degrees in order to pass under a fixed bridge. In Astrakhan the section was once again listed 17 to 20 degrees and towed to Baku.



Section of floating dock being towed to Caspian Sea



Floating Dock Assembled in Baku

When all four sections had arrived the Baku Ship Repair Yard *imeni* Zakavkazskoy Federatsii assembled them into the unit shown in the cut. This is said to be the first of a series of such docks which will be provided for use on the Caspian Sea. In fact, there is some talk of building a special yard on the Caspian to build such docks, but this work would take several years and would cost ten or more millions of rubles.

RAIL-CAR FERRY FOR THE CASPIAN SEA

Construction of the first of four rail-car ferries for the Caspian Sea was begun about two years ago (see the "Journal," November 1958, p. 626) in the Krasnoye Sormovo Shipyard. Recent information is that certain changes have taken place in the original design. Maximum draft, for example, is now set at 14.4 feet, as opposed to the original 15 feet. Too, it was found that it will be necessary to carry all the rail cars on one deck since adding another deck would have resulted in an increase in sail area of the hull which, for the limiting draft on the relatively shallow Caspian Sea, would have been prohibitively high if the ferry was to retain adequate maneuverability. A two-decked vessel, retaining a draft of 13.1 feet, would have an increased height of 19.6 feet and the sail area coefficient would then be 4.7, too great for a seagoing ship.

The ferry will be able to carry any type of rail car, steam locomotive, or other railroad unit, so long as loading does not exceed 12 tons per linear meter. Passenger capacity is given as 290, rather than the 300 originally indicated.

The first of the class will be equipped with 3D100 diesel engines, as planned, and will make 16 knots. Future ships will have 14D100 diesels and speed will be increased to 18 knots, although economical speed will be in the 14-14.5 knot range. Each diesel will be coupled to a reduction gear and will drive an auxiliary, alternating current generator to provide 380 volts at a rating of 200 kilowatts. The three main

motors will be coupled to the shafts as follows: two wing, single-armature type PGK 150/65 main drive motors with a normal rating of 1450-kw at 220-rpm and 500 volts will be fed from individual diesel driven generators; the amidships main drive motor, a double-armature, type 2PGK 150/65 unit, rated at 2x1450-kw at 268-rpm, will operate from two diesel driven generators.

Each winding has a power rating of 1020-kw, so that total propulsion power is 4x1020, or 4080-kw. Increased power will result from the replacement of the 3D100 engines so that, if the 14D100 diesel is used the power output will be increased to 4x1450, or 5800-kw. This increase is desired in order to maintain schedules, regardless of weather, and, in addition, to permit doing upkeep while underway.

The ferries will be equipped with magnetic compasses, a gyrocompass, mechanical and hydro-dynamic logs, fathometer, a radio-navigation station and a radio direction finder.

Hydrofoil Cutter Underway

HYDROFOILS FOR PLEASURE BOATS

The "Krasnoye Sormovo" Shipyard and the Batumi Shipbuilding Yard are engaged in building a series of hydrofoils which can be used on the rivers, and along the seacoasts of the Soviet Union as pleasure craft. The seagoing craft is an off-shoot of the "Krasnoye Sormovo" design for river use and its main elements include:

Length overall, feet	27.9
Beam overall, feet	6.4
Height of side amidships, feet	3.28
Height to top of windshield, feet	4.8
Draft afloat, greatest (to propeller), feet	2.79
Draft underway, on hydrofoils, feet	1.8
Displacement, tons	
Full	1.8
Empty	1.245
Speed at full displacement, miles per hour	37
Fuel supply, gallons	21
Cruising radius, miles	112
Passenger capacity	6

The craft may be operated in 3-foot high waves, when it is possible to attain a speed of 22 miles per hour; the craft will make 30-34 miles per hour in lesser wave conditions.

All main hull parts are of duraluminum, Mark D16A-T (plate) and D16-T (shapes). Bottom plating ranges in thickness from 0.0585" to 0.078" while side and deck plating measures from 0.039" to 0.078". The areas where the foils are joined to the hull range up to 0.117" in thickness.

The hydrofoil installation consists of two bow foils and a stern foil with stabilizer flaps. The elements of the hydrofoils, as given, are:

Foil Characteristics	1st Bow Foil	2nd Bow Foil	Stern Foil
Chord, feet	0.82	0.82	0.82
Span, feet	5.58	5.74	4.40
Area, square feet	4.58	4.84	3.60
V-shaped angle, degree	—2°9′	2°29′	3°15′
Angle of backward sweep, degrees	0	15°40′	0
Relative elongation	6.80	6.81	5.36
Relative profile thickness	0.055	0.055	0.055

The engine, mounted in the stern along with the fuel tank, water filter and coolers, is a converted automobile engine Mark GAZ-652, rated at 77-hp. The reverse-reduction gear and the storage battery are located outside the engine compartment, forward of the engine, under the floorboards, as shown in the cut.

A three-bladed, stainless steel propeller with a diameter of 1.148 feet, a pitch of 1.765 feet and a disc relationship of 0.75 is installed. The reduction gear ratio is 1.55:1.

HYDROFOIL METEOR

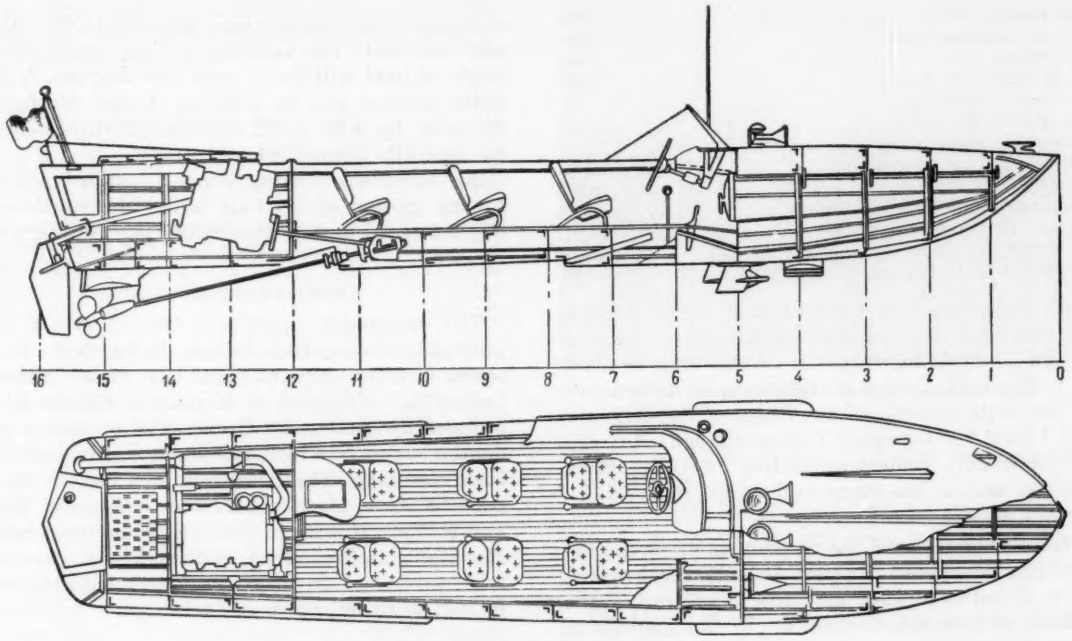
The latest in the family of hydrofoils being produced in the Soviet Union is *Meteor* (see cut), tested under river conditions in November 1959. River tests were followed by tests on the Gorkiy Reservoir, simulating sea trials, and then by actual operational tests on the Azov and Black seas. From the reports, all these tests were satisfactory.

As distinguished from *Raketa,* described in the "Journal," November 1958, p. 621, *Meteor* compares as follows:

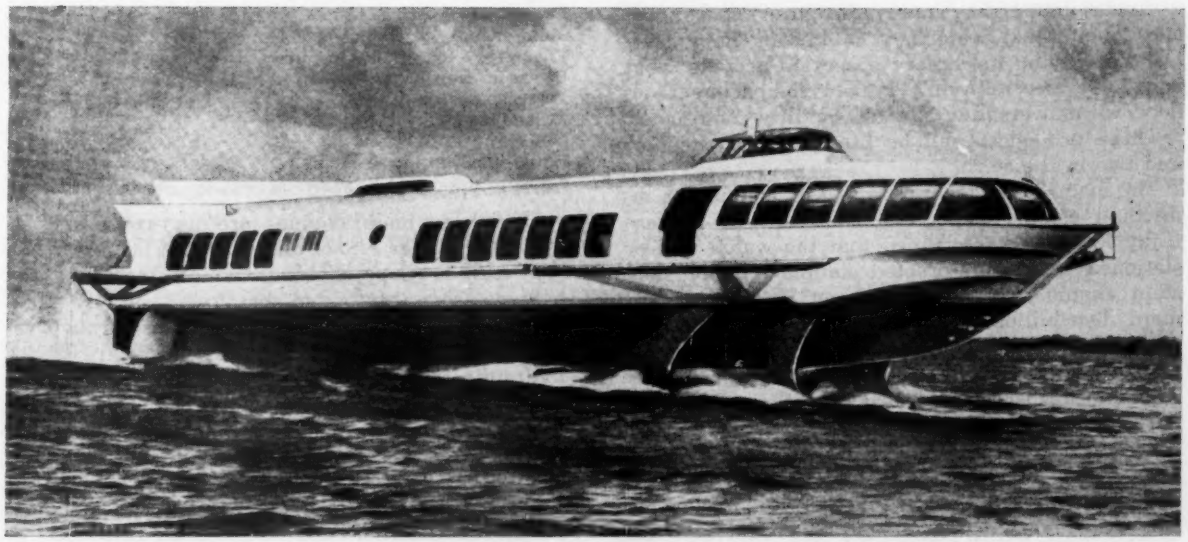
Characteristics	Meteor	Raketa
Length overall, feet	113.0	88.3
Beam overall, feet	19.7	14.4
Draft, underway on foils, feet	3.94	3.6
Displacement, full, tons	52.16	23.0
Main engines, horsepower	2x850	1x900
Speed at full displacement, knots	39	33.1
Maximum speed, knots	44.2	39.1
Passenger capacity:		
Transit use	130	—
Inter-city use	150	66

Meteor is the latest product of the "Krasnoye Sormovo" Shipyard in Gorkiy. The hull is of duraluminum, Mark D-16, and is of riveted construction. An elastic, plastic coating has been applied to the underwater parts to protect against corrosion.

Propulsion is provided by two M-50 diesel engines rated at 850-hp each, with each engine directly coupled to its own shaft. The engines are



Plan Views of Hydrofoil Cutter



The passenger hydrofoil *Meteor* during underway trials

controlled directly from the wheel house through a hydraulic system.

In addition, mention has been made of an even larger hydrofoil, *Sputnik*, which is in the design stage in the same shipyard. It will be more powerful and its speed will be on the order of 55 knots. Capacity will be twice that of *Meteor*. There is further mention of use of hydrofoils to carry cargo, a future development.

PORT ICEBREAKERS

Although there appears to be some confusion concerning the progress being made in the construction of the port icebreakers scheduled for the Admiralty Shipyard in Leningrad, the characteristics for the ship, designed for use in bringing ships through icefields into icebound ports and assisting in port operations, are available as follows:

Length overall, feet	222
Length at waterline, feet	203
Beam overall, feet	59
Beam at waterline, feet	57
Draft, normal, feet	18
Height of side, feet	27
Displacement, normal tons	2718
Propulsion	Diesel-electric
Horsepower	5400
Cruising radius at 13.5 knots, miles	5600
Endurance at full power, days	17
Speed, knots	13.5-14
Crew, including 13 officers	39

Draft limitations, imposed by port water depths, correspondingly limited the weight indices for the ship and limited the selection of the type of steel used in the hull. Design is, however, in accordance with the requirements of the Rules of the Register of the USSR for Category I ships classed ULR 4/1 S (Icebreaker). Protective plating is 0.624" thick amidships and in the stern and 0.700" in the bow. Plating is an alloy steel.

Soviet designers used the theoretical plans for the hull of *Ilya Muromets*, a steam propelled icebreaker built in Sweden in 1941 and now operating in the Far East, as a model. Certain of the flat sections in the original plans were, however, eliminated in order to reduce drag and the hull of the new icebreaker class was streamlined accordingly. The hull is divided into eight main, watertight compartments and longitudinal watertight bulkheads have been installed in the machinery spaces to provide what is called a "second hull." Any one compartment can flood without creating adverse stability conditions.

Three propellers will be fitted, one in the bow and two in the stern.

The main diesel-generators will be installed in individual compartments and controls will be centrally located. It is claimed that the watch will be stationed in a soundproofed station and that constant engine supervision will not be needed. The main distribution switchboard, control panels and the electric motor control station are all located below decks between the diesel-genator compartments.

Propulsion is accomplished by the use of direct-current drive motors, the power supplied from the three main generators, diesel propelled. The aggregate is the 13D100 diesel and the twin-armature generator PN-145, rated at 2x625-kw at 400 volts. The system is flexible enough to provide for (a) operation of one of the two diesel-generators on the bow drive motor, (b) operation of any two diesel-generators on the two stern drive motors, (c) operation of three diesel-generators on the two stern drive-motors and (d) operation of any diesel-generator on the two stern drive motors.

Three ship's service diesel-generators, alternating current, DGT 200/1, with a total power of 600 kilowatts are installed. The prime movers are the 6Ch 25/34 diesels. At anchor power is provided by a standby diesel-generator rated at 100-kw.

A heeling system is installed which will automatically shift ballast from one side to the other in approximately two minutes, during which time the angle of heel will be at least five degrees. A differential system will be used to change the fore and aft draft by 3.28′ in 12 minutes. Both systems will be centrally controlled.

An automatic towing winch, installed aft, has a towing power of 25 tons when the main towing drum is used and 10 tons when the auxiliary drum is used.

RIVER PASSENGER SHIPS

The passenger motorship *Oktyabrskaya Revolyutsiya* (October Revolution) is the first of a new series of river ships to come out of the "Slovenska Lodenitsa" Shipyard in Komarno, Czechoslovakia, ordered by the Soviet Union. The prototype is *Rodina*, a series of which has been, and is, building in East Germany. The new ship is in use on the long runs between Moscow and Astrakhan and Moscow and Rostov. It will, in the future, be used between Moscow and Leningrad. Although the class leader was completed in 1958, its characteristics, which follow, were only recently released:

Length overall, feet	315
Length between perpendiculars, feet	300
Beam overall, feet	49
Height of side, amidships, feet	14
Draft loaded, feet	8
Main engines, 3x525 horsepower	1575
Engine revolutions per minute	480
Speed in deep water, miles per hour	16.8
Passenger capacity:	
Combination	424
Berths	324
Cargo capacity, tons	100-150
Crew	72

The three main engines are non-reversible, 4-cycle, 6-cylinder Skoda diesels, Mark 6C275B, with gas turbine supercharging which increases the horsepower output from 400 to 525 at 480 rpm. Power is transmitted to the propellers through reverse-reduction gearing with a ratio of 1:1.625. A hydraulic friction clutching arrangement serves to couple the engines to the shafts. Remote controls are located in the wheel house.

Propellers are of steel, 5.5 feet in diameter with a pitch of 5.5 feet.

During the 1959 season operations were conducted on an experimental basis and, because of low water conditions on the Danube during downstream passage to the Soviet Union after completion, deep water tests were not conducted. These tests were to have been carried out this past spring on one of the Volga reservoirs.

Yet another passenger type is *Yerofey Khabarov*, built in the Obuda Shipyard in Hungary on plans provided by the Central Planning-Design Bureau of the Ministry for the River Fleet, and in conjunction with the "Leninskaya Kuznitsa" Shipyard. The class is for use in the Amur and Irtyish river basins and is designated as Project 860. A sister ship,

Tyumen, was built in the USSR, and a third, *Dunay,* was also built in the Obuda Shipyard. Characteristics for this class are:

Length overall, feet	252
Length between perpendiculars, feet	244
Beam overall, feet	50
Height of side, feet	11
Draft, empty, feet	4.25
Draft, loaded, feet	4.77
Horsepower, 2x400 Bakau-Wolf diesels	800
Speed, deep water, miles per hour	13
Passenger capacity	308
Displacement, tons	710
Cargo capacity, tons	80-120

The main engines are manufactured by the Karl Libkhecht Works in East Germany and are designated as the R8DF-136, rated at 400-hp at 500-rpm. This is a four-cycle, solid injection, single acting reversible engine. Remote controls are not installed in the first three of the class; the engines are individually controlled in the engine room. However, the first ships developed critical vibration and plans for future ships in the class call for the installation of supercharged engines operating at lower speeds.

Navigation equipment installed in the Soviet Union includes the "Stvor" radar, the "Reka" fathometer and the GOM-4 electric log.

A second series of the same class, building yards not specified, is headed by *Semen Dezhnev* and *Dnepr.*

DIESEL-ELECTRIC DREDGERS

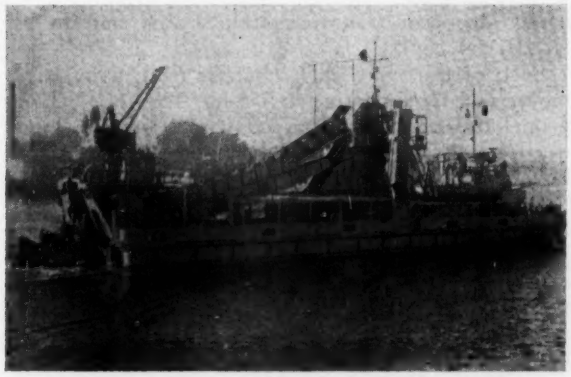
In addition to dredgers from Czechoslovakia (see the "Journal," November 1959, p. 707), the Soviet Union has contracts with East Germany to provide multi-bucket, diesel-electric propelled dredgers with a capacity for handling 523 cubic yards of material per hour. (See cut). The building yard is in Rosslau and construction is in accordance with the Rules for the Maritime Register of the USSR, Class R 4/1S.

The first two units, *Kuban-1* and *Turali,* went into service last year and the characteristics, as published, are:

Length overall, feet	183
Beam overall, feet	32
Height of side, feet	13
Draft, feet	8.2
Displacement, tons	1000
Speed at draft of 8.2', miles per hour	6
Dredging depth, feet	39-46
Crew members	39

The hull is of all-welded construction and is divided by watertight bulkheads into seven compartments. A double bottom extends the entire length of the hull and provides storage space for fuel, water and ballast. The fuel supply is adequate for 15 days of continuous operation.

The main propulsion plant consists of two diesels, model 6DV-136, rated at 300-hp at 500-rpm, driving 200-kw generators at 230 volts. The steel propellers can be driven at 375-rpm off the main drive motors,



East German-built Diesel-Electric Dredger

which are direct current, 140-kw, through reduction gearing.

Dredgers to be delivered in the period 1961-1965 will have automatic and remote controls for the power plant and many of the operations now done by hand will be mechanized.

The Omsk Ship Repair Yard, on the Irtyish River, has built a smaller version of this multi-bucket, diesel-electric dredger. The Omsk version will handle 327 cubic yards of heavy material at a depth of up to 26 feet. The first unit off the production line has been named *Irtyishkiy-4.* This latest addition to the dredger fleet on the Irtyish River can, it is said, be operated by one man from either the main, or the auxiliary, control station.

LENIN-CLASS PASSENGER SHIP

This class of river passenger ship was mentioned briefly in the May 1958 issue of the "Journal," page 214. Additional information on the class includes:

Height of side, feet	16.4
Draft at full load, feet	7.86
Coefficient of form:	
α	0.84
β	0.92
γ	0.66
Displacement, tons	2320
Passenger capacity	439

Only two of the class are known to be in service, *Lenin* and *Sovetskiy Soyuz,* both of which were built in the "Krasnoye Sormovo" *imeni* A. A. Zhdanov Shipyard. Both are classed in the River Register as Category "O" (Lake).

Main and auxiliary machinery controls are located at a central station on a platform in the engine room. Each of the three units used for propulsion consists of a six-cylinder diesel, Mark D-50, supercharged, rated at 900-hp at 720-rpm. The prime mover is connected, through a flexible coupling, to a direct current generator, Type MPG 84/39, rated at 605-kw at 720-rpm. At full power, 1800-kw, hourly fuel consumption is 6.34 ounces per horsepower and efficiency of the plant, taking into ac-

count electrical transmission losses, is said to be 83-83.5 per cent.

Each of the three shafts has its own main drive motor and motor rating is 750-hp. The four-bladed propellers originally installed were found to have caused excessive vibration throughout the ship and have been replaced by three-bladed propellers which are 5.5 feet in diameter and have a pitch of 5.1 feet. Use of the new propellers, with the amidships unit making 357-rpm and the outboard units making 362-rpm, resulted in a speed of 16.8 miles per hour, as against the 15 miles per hour originally indicated.

Kirgizstan-CLASS PROPULSION INSTALLATION

Kirgizstan, first of a series of passenger ships built on the Baltic for use on the Caspian Sea, has two 8DR 43/61 diesel engines for main propulsion use. This model engine is rated at 2000-hp at 250-rpm, and is a product of the "Russkiy Dizel" Works.

Trials of the vessel were interesting because this is the first time that this particular model engine has been used in a twin screw ship; each engine is directly coupled to its individual shaft. Turns, fuel consumption and other thermal parameters were measured at all speeds, up to overload, and down to the minimum turns possible without stalling the engines. Standards established in the factory on test stands were used during the trials for comparative purposes.

During underway trials it was found that standards for maximum combustion pressures and average exhaust temperatures were attained at 234-rpm for the port engine and 238-rpm for the starboard engine, at which turns the engines developed 1775 and 1760 effective horsepower, respectively. Fuel consumption was 5.9 ounces and 5.7 ounces per horsepower per hour, respectively, at this speed. At full power it was found that the port engine developed 1970-ehp at 250 rpm, consuming 5.8 ounces of fuel per horsepower per hour, while the starboard engine, although developing 2130-ehp at the speed, could do no better than 244-rpm. At this speed consumption of fuel was at the rate of 6.1 grams per horsepower per hour.

The difficulty on the starboard side appears to have been the result of incorrect propeller installation, or perhaps of damage to the propeller during the trials.

Backing down was carried out from between 21 seconds to 1 minute 36 seconds, time intervals which, although within the limits permitted by the Register of the USSR, are considered to be excessive. No difference in time was noted for moving from "full ahead" to "full astern" from either the remote control station or from the engine room control station.

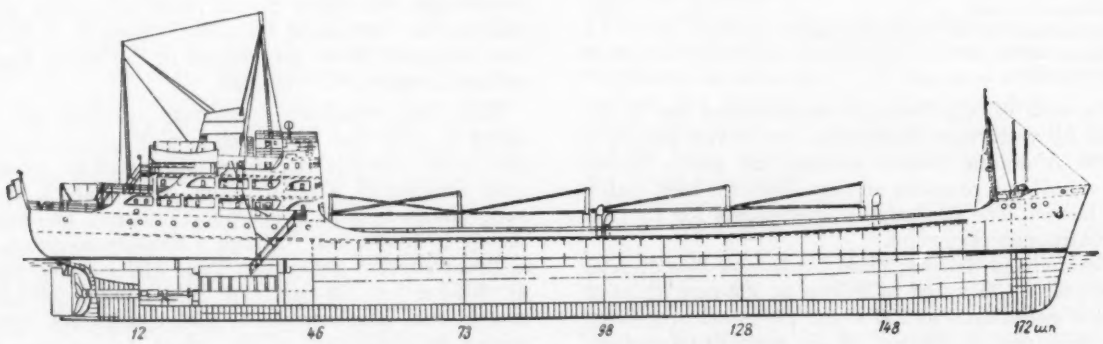
COAL-ORE CARRIERS

The Varnow Shipyard in East Germany has been building a series of coal-ore carriers for the Soviet Union which are capable of carrying some 6400 tons of cargo. The first of the class, *Ugleuralsk*, was delivered in 1958 and since that time nine additional ships of the class have been turned over to the Soviet Union.

Specifications for construction are those of the Register of the USSR and the ships bear the Register classification UL R 4/1 S (ore carrier). Characteristics of the class include:

Length overall, feet	440
Length between perpendiculars, feet	413
Beam amidships, feet	56
Height of side to main deck, feet	31
Draft at full load:	
in sea water, feet	24
in fresh water, feet	25
Displacement at 24′ draft, tons	11080
Deadweight at 24′ draft, tons	7184
Useful cargo capacity over 6000 miles, tons	6398
GRT	5628
Speed at 110-rpm, knots	15.51
EHP at 110-rpm	4700
Crew	34

Hull structure is such that the class can easily operate astern of an icebreaker in any ice conditions, as well as independently in thin ice. The hull is divided into eight watertight compartments, any one of which can be flooded without danger to stability. Holds 2 and 5 are built with smooth surfaces



View of the coal-ore carrier of the *Ugleuralsk* class

in order to facilitate the loading and unloading of ore and coal. All hatches are fitted with MacGregor, quick-closing covers.

The main engine is a 7-cylinder, two-cycle, MAN diesel, Mark K7Z70/120C, certain of the characteristics of which are:

Effective horsepower at 115-rpm	5400
Effective horsepower at 110-rpm	4700
Engine weight, dry, tons	366
Fuel consumption, 110-rpm, ounces/ehp/hour	5.5
Supercharged, air start	

The bronze propeller, right-hand rotation, is 17 feet in diameter, four-bladed, weighing approximately 10 tons and has an efficiency rating of 0.636. Pitch is 14.2 feet and the disc relationship is 0.40. The developed thrust is approximately 92,000 pounds. A spare propeller, made of steel and with detachable blades, is carried on board.

While the class is operating successfully, most of them with the Black Sea Steamship Company, tests of the first of the class, *Ugleuralsk,* conducted in the summer of 1959, turned up certain design faults which will need correction. *Ugleuralsk* failed to measure up to seakeeping characteristics expected of ships of modern design and construction. Above 13.5 knots loss of speed and excessive drag developed. Soviet naval architects believe that reducing the 17° angle of the hull at the waterline at full load to 12° will correct this fault. Under actual operating conditions, with the ship loaded to a mean draft of 23.3 feet, a speed of 14.7 knots was made with the engine operating for 115 shaft revolutions. At this speed developed horsepower was 5260.

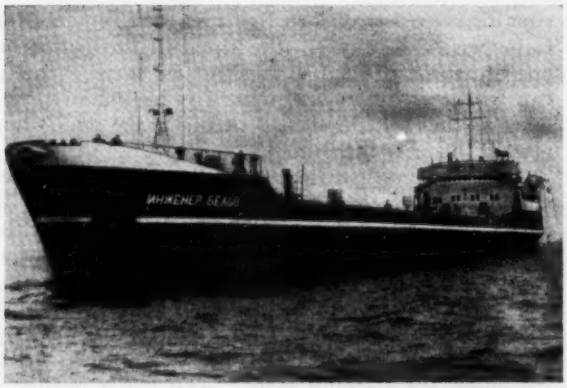
Comparative tests were made in calm water, during which it was found that the rated horsepower of 4700 could be attained at 111.5-rpm, resulting in a speed of 14.5 knots. The time to go from "full ahead" to "full astern" was 3 minutes 13 seconds, during which time the ahead reach was 230 feet, or little more than half a ship's length.

The critical speed range, both ahead and astern, was found between 75-95 rpm, causing much concern because, in rough weather, normal speeds are right in this range. When backing down, "full astern" falls in the 90-95 rpm range. This fault, in addition to causing real operating difficulties, results in more than normal vibration of the hull when passing through the critical range.

Finally, the installed cargo handling gear was found to be too light for rapid operations.

COTTON-TIMBER CARRIERS

Inzhener Belov (see cut) is the first of a new series of cotton-timber carriers to come out of the Navashino Shipyard for use on the Caspian Sea. The new class is build on slightly modified *Oleg Koshevoy* tanker class specifications, as may be seen from the comparative figures which follow for the two classes:



The Soviet-built Cotton-Timber Carrier *Inzhener Belov*

	Belov	*Koshevoy*
Length overall, feet	394	405
Beam overall, feet	49	52
Height of side, feet	21	18
Capacity at 10.5′ draft, tons	2500	2600
Capacity at 13′ draft (sea), tons	3700	4000
Full displacement, tons	5327	6030
Mean draft at full displacement, feet	13	13
Crew	27	44

The new ship is an all-welded one, carrying two modernized versions of the Mark 8DR 30/50 diesel engine for main propulsion. The new model is designated 8DR 30/50 M55 and has a rating of 800-ehp at 300-rpm. The engines are clutched to the shaft and the propellers are shrouded.

Three of the class have been anonunced, one of which has been built with rudders rather than directional shrouds in order to arrive at comparative efficiencies of the two types of steering control.

All have quick-closing hatch covers. Three diesel-generators, alternating current, 230 volts, 65-kw, can be paralleled on the main distribution switchboard to serve the ship's service network.

RIVER DRY-CARGO MOTORSHIP

The *Shestaya Pyatiletka* (Sixth Five-Year Plan) is the first of a series of dry-cargo motorships which have been built in the "Krasnoye Sormovo" *imeni* A. A. Khdanov shipyard and is a modernized version of a series built between 1948 and 1953. However, the volume of modernization work was so great that only the theoretical plans and the basic dimensions of the original project were retained. Present elements of the design are:

Length overall, feet	306
Length between perpendiculars, feet	295
Beam, feet	42.6
Height of side, feet	15.7
Draft, full load, feet	9.2
Cargo capacity at draft of 9.2′, tons	2000
Displacement, tons	2740
Speed, miles per hour	12.5

Construction is in accordance with Register requirements for Category "O" (Lake). If operating

conditions correspond to Register requirements for Category "R" (River), the ships in the class can operate at a draft of 10.5 feet and the cargo capacity can be increased to 2400 tons. The hull is strengthened so that the ships can operate in ice which has already been broken up.

The machinery spaces and the superstructure, which contains the living spaces for a crew of 24 and 4 students, are located aft. The four cargo holds, all forward of the superstructure, extend over a length of 216 feet. A double bottom under the holds will take from 700 to 800 tons of liquid ballast which is used to equalize the draft when loaded and to protect the hull against hogging or sagging when the ships are running empty. The hatch openings are 28.8 feet on a side and, compared with the earlier class, open up 70 percent more deck. There are no pillars in the holds.

Main propulsion is provided by two Bukau-Wolf diesels, Mark R6DF-148, rated at 500-hp each at 350-rpm, directly coupled to the shafts. Propellers are four-bladed. Controls are located in the wheel house.

The starboard shaft carries a direct current generator rated at 23.5-kw at 220 volts and is designated as Type PN-200. When the ship is underway this generator provides for ship's service needs. Voltage regulation is accomplished for all speeds from full down to half ahead. Below this range, down to slow speed, or when stopped, a standby generator cuts in automatically within 7-10 seconds. There are two such generators, diesel driven by type 4Ch-10.5/13 engines rated at 40-hp at 1500-rpm. In the interval between changeover, a storage battery installation, 220-volts and 45-ampere-hours, cuts over to the switchboard bus bars automatically. Battery charging is done from the underway generator. An alternating current supply is also available for limited use.

Whereas the previous class had been fitted with three rudders, this class is fitted with rotatable, directional shrouds.

ROADSTEAD TANKER

The first of a series of small, roadstead-type tankers, of 500 tons capacity is presently in service and bears the designation *MNS-11500*. This is a single-decked, single-screw motorship with four cargo tanks. The engine and pump rooms are aft.

Built to ice classification in the Register of the USSR, the tanker can operate in broken ice in harbors and roadsteads, and was designed to fuel ships in such areas. Certain of the characteristics are:

Length overall, feet	173
Beam overall, feet	30
Height of side, feet	11
Full displacement, tons	980
Mean draft at full displacement, feet	10
Crew accomodations	18

Hull and superstructure are of all-welded, steel construction.

The main engine is a Mark 6SChP 23/30 diesel engine rated at 450-hp at 1000-rpm. A geared-reduction couples the engine to the shaft and reduces engine turns to 338 shaft turns, maximum. The propeller is shrouded and four radial fins, fitted to the external surface of the shrouding, assist in maintaining steering control. Movement of the shrouding is controlled through a combination electrical and hand steering engine Mark REGZ-2.

All auxiliaries, with the exception of the cargo pumps, are electrically driven. The cargo pumps are steam propelled. Fire protection is provided by water, carbon dioxide, and steam smothering systems, as well as by a system of liquid chemical-steam smothering not otherwise described.

SEAGOING TRAWLERS

Okean is the name of the first of a long series of medium sized fishing trawlers contracted for by the Soviet Union in East Germany and built in Stralsund, commencing about 1958. The basic characteristics of the class are:

Length overall, feet	166
Length between perpendiculars, feet	145
Beam overall, feet	29
Height of side, amidships, feet	14
Draft at full displacement, feet	11
Full displacement, tons	748
Main engine (Mark R8DV-148), ehp at 275-rpm	540

Trawlers of this type, which have the engine coupled directly to the shaft, when operating at normal working speeds of from 2.5 to 4 knots, waste a considerable part of installed power because, at these speeds, the engines are operating at about 80 per cent of their rated capacities. In an effort to arrive at a better arrangement, East German engineers, in the course of 1957, conducted experimental work on a fishing vessel with the designation

Dual, welded steel propeller

SAS-216, which was fitted with the usual three-bladed propeller, then with a dual, or tandem propeller (see cut). Results with the latter proved to be sufficiently interesting to fit *Okean* with the experimental model, again for comparative purposes.

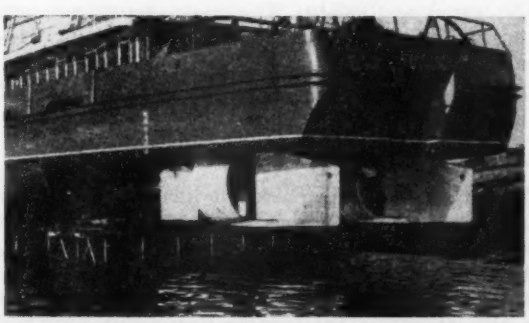
Two propellers were manufactured for *Okean.* One was the usual steel, three-bladed type, the other a steel, welded, dual, six-bladed propeller. The comparative figures for the two follow:

	3-bladed	Dual
Diameter, inches	721.5	702.0
Pitch, inches	64.9	51.9 (forward) 56.9 (aft)
Pitch proportion	0.9	0.74 (forward) 0.81 (aft)
Disc relationship	0.5	0.35 (both)
Weight, pounds	1363	1255
Rotation	Right	Right

Ordinarily, because of the severe corrosion encountered in the use of cast steel propellers, and the correspondingly short periods of service obtained by trawlers and other fishing vessels using this type, stainless steel is recommended. In fact, the "Leninskya Kuznitsa" Shipyard, Kiev, a building yard for medium fishing trawlers, has gone to stainless steel propellers as a regular practice. In addition, it appears to be Soviet practice to use welded steel propellers for small ships only.

Okean was used as a test vehicle because results obtained in 1957 with the use of the dual propeller were so favorable, rather than because a propeller of this type satisfied trawler requirements as proven in practice. The North Sea was chosen as the testing grounds.

Almost at once, however, tests were called off as severe vibration developed after the dual propeller had been installed. Preliminary tests had indicated that there was little to choose from, so far as towing and speed characteristics were concerned, between the two types. However, when investigation revealed that the vibration had resulted from a blade having broken off as a result of a welding fault, it was decided that this type of propeller needed further study.



Stern view of push tug *Lyublin* showing unsatisfactory rudder design

TUG-PUSHER *Lyublin*

The new, experimental, tug-pusher *Lyublin* was turned over to the Volga Tanker Steamship Line during the 1959 season, ready for operational use. The new tug-pusher is basically similar to the *Plevna*-class described in the JOURNAL, February 1960, p. 177. Main differences are in the rudder installation (see cut) and in the electrical equipment and instruments connected with the installation.

Lyublin is a twin-screw, lake-type tug-pusher with wheel-houses on the main, boat, and upper decks. The hull is strengthened for ice use and is designated as a "Lake" type ship in the Register of the USSR for use on the Volga and Kama rivers.

This is the first of a number of tug-pushers in the 1340-hp class and is equipped with rudders rather than with directional nozzles, as had been the case with smaller, previously built units. During trial runs operation in the ahead direction was satisfactory, but in the astern direction the pusher did not respond to her rudders, either when coupled to a barge, or when operating independently.

Several trips were made to the yard to change the rudder area, increasing and decreasing the area as suggested by trials and, apparently, errors. Nothing worked. It was also found that the speed obtained, both pushing and towing, was lower with the rudder installation than with nozzles.

Soviet designers indicate they will return to the directional nozzle design in future tug-pushers.

SALVAGE-RESCUE SHIP

Pamir (see cut) is one of four rescue ships built in Gefle, Sweden, for the Soviet Union during the period 1958-1959. The others are *Aldan, Agatan,* and *Arban.* Their intended use is to assist ships which have gotten into difficulties on the high seas, on inland seas, and along the coastal areas. They are equipped to seek out ships in distress, to tow ships of any displacement, to break ice, and to carry on ship salvage and diving work in water depths of from 197 to 262 feet.

Although the ship was built to class in Lloyd's Register (100A1), its stability is in conformity with the "Temporary Norms for Stability of Merchant Ships" of the Register of the USSR, published in 1948.

Characteristics of the class include:

Length overall, feet	256
Length between perpendiculars, feet	236
Beam overall, feet	42.2
Height of side amidships, feet	17
Full displacement, tons	2032
Mean draft at full displacement, feet	13.4
Main engine, ehp (2x2100)	4200
Full speed, knots	17.5
Economical speed, knots	12.8
Cruising radius at full speed, miles	15200
Cruising radius at economical speed, miles	21800
Endurance with full stores, days	30
Crew	71

Swedish-built Soviet Rescue Ship *Pamir*

The ship can deckload 15 tons aft and 10 tons on the forecastle and still retain her stability if an additional loading of ice of as much as 50 tons is taken on on the decks, superstructure and rigging. One hold forward can take 50 tons and one aft will hold 120 tons of cargo. Fuel tanks will load 350 tons, while fresh water capacity is 90 tons. Installed evaporators will make 4.5 tons of water a day.

The crew is housed in 1, 2, 4 and 6 place cabins, while the salvage party is housed under the upper deck in two spare bunkrooms for 8 and 18 men each.

Main propulsion is provided by two 10-cylinder MAN engines rated at 2100-ehp each at 275-rpm. Shafts carry variable pitch propellers; propeller diameter is 8.2 feet and the three blades, made of stainless steel, are removable.

Remote engine controls are located in the wheel house, as are the controls for the variable pitch propellers. A second control station is located on the upper bridge, with a third station in the engine room. Engine control can be accomplished only from the main control station in the wheel house, however.

The ship's service and emergency electrical power installation is made up of five diesel-generators, alternating current, at 380 volts. Three are rated at 160-kw, two at 75-kw. Three transformers supply the 220 volts used on the ships network. Power can be fed to other ships at 380 and 220 volts AC and 220 and 110 volts DC.

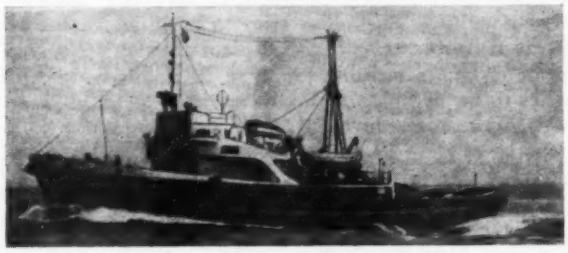
Yet another class of salvage-rescue vessel is headed by *Atlant* (see cut), a 2000-hp unit which is designed as well for icebreaking, towing and harbor work. The single-decked ship is diesel-electric propelled and is classed in the Register of the USSR as UL R 4/1 S (Tug). Its characteristics include:

Length overall, feet	172
Length between perpendiculars, feet	156
Beam overall (including rubbing strakes), feet	38
Height of side amidships, feet	19
Designed draft, feet	15
Displacement, tons	1190
Horsepower, rated	2000
Speed, knots	14
Towing pull at 7 knots, tons	14

The normal supply of fuel, water and lube oil will permit operations for a period of 20 days at full power. The operating area is unlimited and stability is such that the ship will remain unaffected with one compartment flooded. A 26 man crew and salvage party is carried in one, two and four place cabins.

The ship is equipped with big pumps, portable handy billies, foam generators and tanks containing liquid foam for fire fighting. Monitors can throw streams of water 165 feet. Drainage and salvage pumps, stationary and portable, 18 in all, can handle a total of 550,000 gallons of liquid per hour.

The tug is equipped with diving gear and compressors for providing the divers with air, as well as equipment for underwater work involved in washing under a vessel aground, for electric welding and cutting and other operations.



The Salvage-Rescue Tug *Atlant*

Communications installations include two all-wave receivers, an emergency transmitter, emergency receiver, an automatic receiver for distress signals, automatic alarm, a radio-telephone installation of the "Urozhay" type and boat radio stations. The radar is the "Don," which is said to pick up targets at 40 miles, and an RDF installation.

Two diesel-generators, direct current, provide power for the one main drive motor which has a constant power rating of 1400-kw at a voltage of 920 and which makes 213-rpm. The diesels are type 5D50, rated at 1000-hp. The main generators are rated at 760-kw, continuous duty, 460 volts, 740-rpm.

The propeller is four-bladed, with a diameter of 10.8 feet and a pitch of 6.46 feet.

WAGE SCALES IN THE MERCHANT MARINE

New types of ships, modern installations, more complex equipment, have all resulted in an increased need for more highly qualified specialists, both on the bridges and in the engine rooms, of Soviet merchant ships. Wages in the merchant marine are now reflecting the greater knowledge required for various groups of deck and engineering personnel.

Seamen afloat are divided into eight pay groupings, while shore workers have ten such groupings, all based on differences in ships and in categories of enterprises. For example, certain crew members are paid by gross registered tonnage, others by horsepower of the main plant, still others by electrical power, etc.

From the standpoint of gross registered tonnage, ships have been grouped into 7 categories, rather than the former 11, as follows:

Group	*GRT*	*HP*
1	up to 300	up to 300
2	301-1500	301-1200
3	1501-2500	1201-2000
4	2501-5000	2001-4000
5	5001-10000	4001-8000
6	10001-20000	8001-16000
7	over 20000	over 16000

What this all means may be seen from the following example. Let us take a dry-cargo ship assigned to the Black Sea Steamship Company which is listed at 10,000 GRT, with a main propulsion plant rated at 5000-hp. Under the old pay scale the captain received a base pay of 1400 rubles a month and a longevity payment of 340 rubbles, for a total of 1740 rubles. Under the new pay scale he will receive 2300 rubles, total. The second mate on this ship will be raised from 1025 to 1450 rubles. The chief engineer will jump from 1640 to 2100 rubles, while the second assistant engineer will move from 1210 to 1700 rubles.

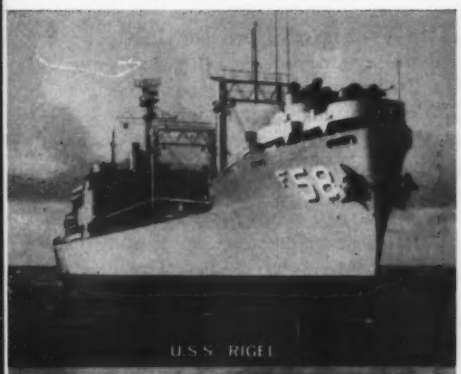
The accepted conversion is four rubles to the dollar, but it may be recalled that the so-called "tourist" rate is quoted as ten rubles to the dollar.

RUSSIAN MERCHANT FLEET

The statistical tables of Lloyd's Register of Shipping suggest that the existing Russian merchant fleet totals rather more than 3,000,000 tons, thus placing the U.S.S.R. well down on the list of the world's maritime powers. There has been more than one sign in recent months, however, that the Russians are taking an increasing interest in maritime trade, and in a speech delivered before the Senate of the United States, Senator Warren G. Magnuson has suggested that at the rate at which the U.S.S.R. is currently building ships her merchant fleet will exceed 13,000,000 tons in 15 years' time. In Senator Magnuson's view this expansion will intensify the cold war, and it is certainly a development that will engage the attention of all maritime powers. Hitherto the U.S.S.R. has been thought of principally as a land power. Will she, within a decade or so, become one of the three major maritime powers? Senator Magnuson sees the possibility as part of the U.S.S.R.'s strategy for world domination. "What better way," he asks, "could they proceed to 'bury' us and the rest of the Free World economically, than to drive other merchant shipping off the seas through devastating undercutting of rates, through dumping strategic materials on world markets at bargain-basement prices?" A substantial Russian fleet, he believes, would also be used to supply and sustain revolutionary movements abroad, as it has been used already to supply arms to Egypt, to send Kurdish tribesmen to Iraq, and to penetrate economically into the Yemen. With her 500 submarines, Senator Magnuson already sees the U.S.S.R. as a sea power second only to the United States herself, and he points out that a 12-mile territorial water limit adds "3,000,000 miles of additional coastal territory" to the Soviet Union. Both the RB-47 incident and events in Cuba lend substance to the Senator's fears.

—Shipbuilding and Shipping Record, July 21, 1960

In the service of pleasure...commerce...national defense


U.S.S. RIGEL

S.S. KYMO

S.S. ROTTERDAM

S.S. MORMACPRIDE

S.S. WORLD BEAUTY

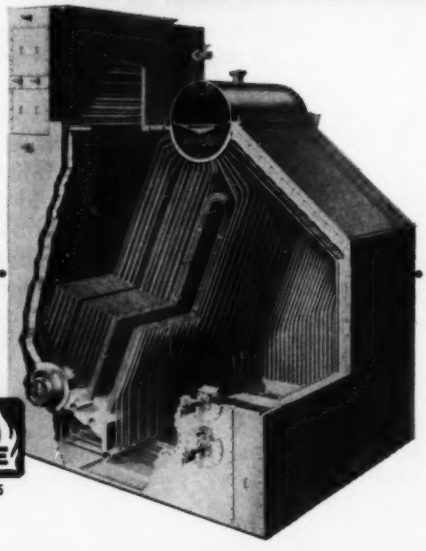
S.S. EDMUND FITZGERALD

U.S.S. SURIBACHI

S.S. ANDROS CITY

...ships of all types are powered by

C-E V2M Vertical Superheater Boilers


C-275

COMBUSTION ENGINEERING

General Offices: Windsor, Conn.
New York Offices: 200 Madison Ave., New York 16
CANADA: Combustion Engineering-Superheater Ltd.

ALL TYPES OF STEAM GENERATING, FUEL BURNING AND RELATED EQUIPMENT; NUCLEAR REACTORS; PAPER MILL EQUIPMENT; PULVERIZERS; FLASH DRYING SYSTEMS; PRESSURE VESSELS; SOIL PIPE

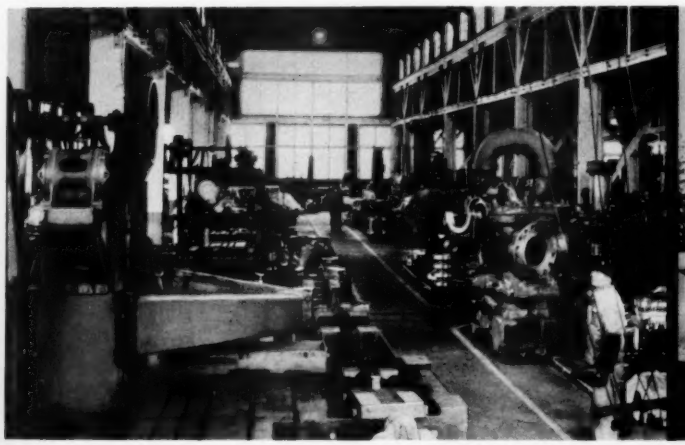
YOUR GUIDE TO WORTHINGTON MARINE SERVICE AROUND THE WORLD

When your marine auxiliaries are built by Worthington, you can count on finding identical services at the world's most important ports. And Worthington marine products are interchangeable because they duplicate American designs and are built to American standards everywhere. Thus you can standardize with Worthington.

The pictures on these pages show 10 of Worthington's manufacturing plants spread around the globe. These plants are geared to handle repair or rebuilding of most Worthington marine products. In an emergency, a nearby Worthington plant will cut costly in-port time to a minimum.

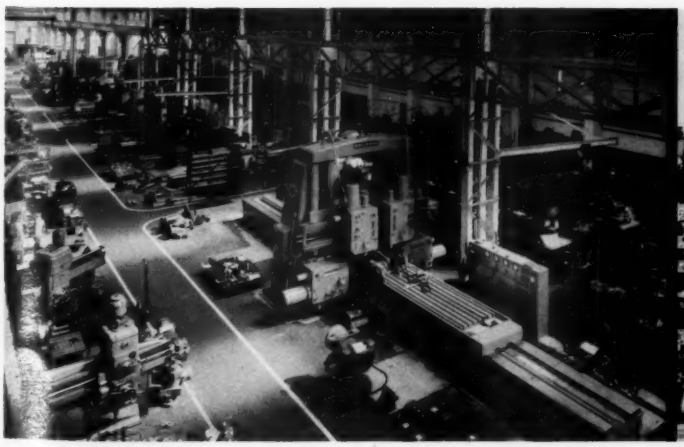
We would like to send you more information about Worthington's complete line of shipboard auxiliaries. They include pumps, compressors, steam turbines, diesel engines, condensers, deaerators, ejectors, and air conditioning and refrigeration equipment. Please write to R. H. Davis, Worthington Corporation, Section 106-6, Harrison, New Jersey.

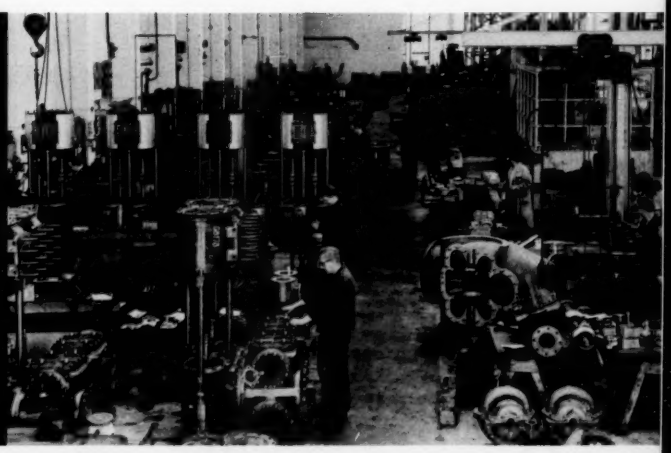
WORTHINGTON

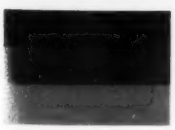


Tokyo, Japan. Niigata Worthington manufactures almost a full line of marine equipment. Since 1953 thousands of tons of shipping built in Japanese yards have gone to sea with Niigata Worthington products. Engineers and technicians trained in the U.S.A. assure prompt and efficient marine service.

Brantford, Ont., Canada. 60 miles west of Toronto is this modern Worthington factory containing 60,000 sq. ft. of space. Here Worthington manufactures shipboard equipment and provides marine service.

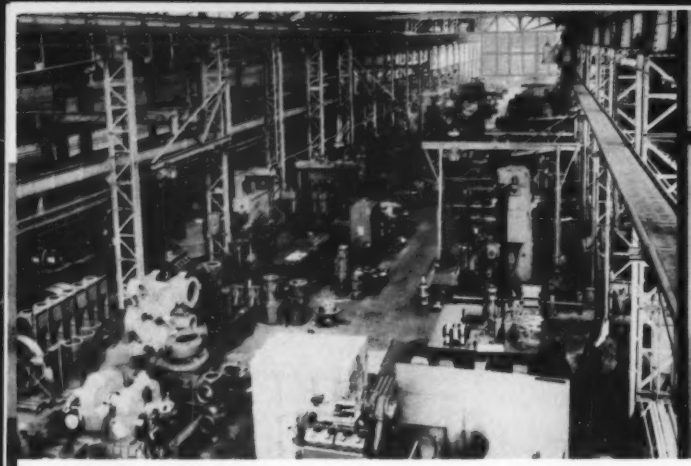


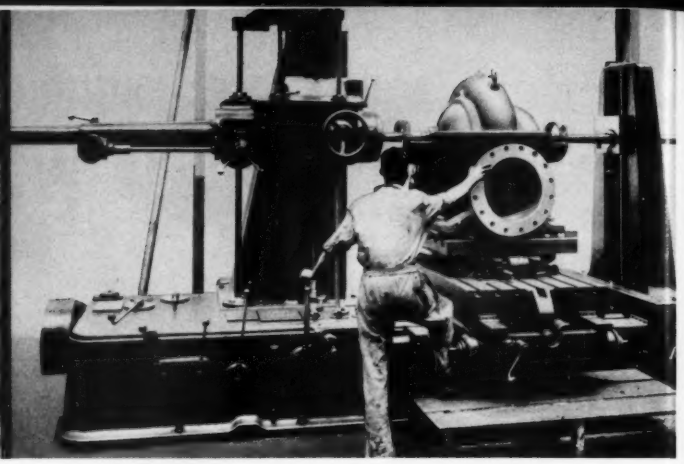




Hamburg, Germany. Worthington has manufactured marine equipment in Germany for more than half a century. After the war, operations were transferred to a new plant in Hamburg. Completely equipped with modern precision machinery, Worthington builds pumps, compressors and deaerators here.

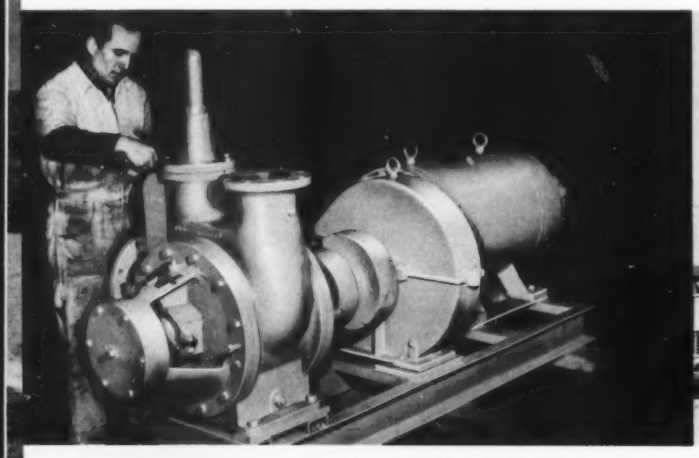
Milan, Italy. One of Worthington's largest on the continent, this plant recently supplied almost all the pumps for twelve 36,000 ton tankers. Builder of a varied line of pumps, compressors, turbines and refrigeration equipment, this plant as well as a new factory in Naples can handle all types of marine service work.



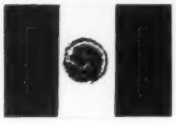


Le Bourget, France. Completely equipped with the latest modern machinery, Société Worthington manufactures a complete line of marine products in a 20-acre plant near the famous Le Bourget airfield, four miles from Paris. This plant can give day or night service on Worthington marine products.

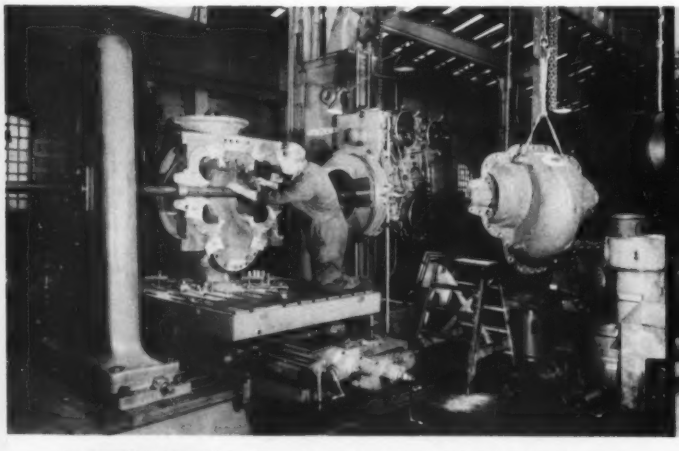
Madrid, Spain. This new plant in an outlying section of Madrid was built in 1954. Offering a broad line of shipboard equipment, this plant has furnished auxiliaries for 90% of the ships built in Spanish yards. This modern plant, with up-to-date machine tools and a large test stand, can give fast, efficient service on all types of Worthington equipment.



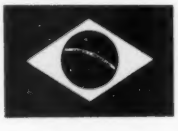
Buenos Aires, Argentina. Worthington manufactures pumping equipment in this plant in Buenos Aires. The facilities here can provide emergency service when needed by ships calling at the nearby port.



Mexico D.F., Mexico. Worthington began manufacturing in Mexico City in 1950. Several expansions followed, until today the plant is equipped to repair and service most Worthington equipment.



Newark-on-Trent, Great Britain. 1200 employees operate this Worthington-Simpson plant. This completely integrated operation includes foundry, welding shop, plate shop, machine shops, and complete test facilities. It is ideally suited to handle marine service, repair or rebuilding.



Rio de Janeiro, Brazil. Operated by technicians trained to U.S. standards, the new Rio plant builds marine pumps and compressors from Worthington drawings and specifications. Branch offices also help to assure you of fast service in Brazil.

LIEUTENANT ALBERT G. STIRLING, U.S.C.G.

BASIC CONTROL CONCEPTS FOR PRESSURIZED WATER REACTORS

THE AUTHOR

is a graduate of the Coast Guard Academy class of 1953. His four years of sea duty was divided into one year on deck and three years in engineering of which one year was as Engineering Officer of the Coast Guard Cutter Matagorda (WAVP-373). He has been assigned to the Massachusetts Institute of Technology since 1957 until graduating in June 1960 with the degree of Science Master in Naval Architecture and Marine Engineering and the degree of Naval Engineer.

A great deal has been written about the various types of nuclear reactors and the physics which make the reactors possible. But how is this new power source controlled to give satisfactory marine service? This paper attempts to give some insight into the control problems of a typical pressurized water reactor in use by the Navy. This will be a very elementary discussion of the basic control concepts of an operating reactor. Such details as start-up and actual control circuits will not be covered.

To assist in clarity and to eliminate confusion, some definitions as used in this paper are given.

The multiplication factor (k) is the number of neutrons produced per fission which are capable of producing another fission. k usually refers to an infinite reactor, however, in this paper it shall refer to k_{eff}, the multiplication factor for a finite reactor. When k=1, k >1, or k < 1, the reactor is said to be critical (steady state), super-critical (increasing its power output), or subcritical (decreasing its power output) respectively.

The neutron lifetime (L) is the average time between successive neutron generations. The mean effective lifetime (L*) is equal to L/k for large reactors only. [1, 4]

From the above definitions it is easily seen that the rate of change of neutrons per unit time is:

$$\frac{dn}{dt} = \frac{\delta k}{L^*} n \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

integrating:

$$n = n_o e^{(\frac{\delta k}{L^*})t} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

One final definition is that of the reactor period (T)

SYMBOLS

C_i = Concentration of the delayed neutrons of the ith group due to previous fissions

$$\frac{dC_i}{dt} = \frac{\beta_i}{L^*} n - \lambda_i C_i$$

I = Concentration of Iodine at time t
k = Multiplication of factor for an infinite reactor
k_{eff} = Multiplication factor for a finite reactor
δk = reactivity
L = Nuetron lifetime
L^* = Mean effective neutron lifetime for large reactors, $L^* = L/k$
n = Number of neutrons at time t
n = Number of neutrons at time t=0
P_s = Steam pressure in secondary loop
T = Period of reactor
T_h = Temperature out of reactor (hot)
T_c = Temperature into reactor (cold)
T_{avg} = Average temperature in reactor,

$$T_{avg} = \frac{T_h + T_c}{2}$$

T_s = Steam temperature in secondary loop
t = Time
X = Xenon concentration

GREEK LETTERS

β_i = Fraction of delayed neutrons in the ith group
β = Total fraction of delayed neutrons, approximately 0.0075
δk = Reactivity
γ_x = Fractional yield of xenon as direct fission product
λ = Average decay constant for all delayed neutrons ≈ 0.1 sec^{-1}.
λ_I = Decay constant for iodine
λ_x = Decay constant for xenon
Σ_f = Macroscopic fission cross-section of reactor fuel
σ_a = Microscopic absorption cross-section of xenon
φ = Neutron flux in reactor

$$T = \frac{1}{\frac{1}{r}\frac{dn}{dt}} \quad \ldots\ldots (3)$$

and substituting from equation (1):

$$T = L^*/\delta k \quad \ldots\ldots (3a)$$

This result, combined with equation (2), allows an alternate definition which is: the period is the time required for the neutron level to change by a factor of e (2.718).

The most important factor in reactor control, indeed the phenomenon which enables a nuclear chain reaction to be controlled, is that of the delayed neutrons. Nuclear fission produces neutrons in two forms. Prompt neutrons appear as an immediate fission product, while the delayed neutrons appear from the decay of the radioactive fission products. These delayed neutrons may be divided into six subgroups, but for simplicity this discussion shall consider them as one group constituting approximately 0.75 per cent of the total neutrons and appearing with an average decay constant of 0.1 $sec.^{-1}$

The effect of these delayed neutrons is best shown by an example. Equation (1) is for prompt neutrons. If delayed neutrons are considered, equation (1) becomes [4]

$$\frac{dn}{dt} = \frac{\delta k}{L^*} n - \frac{\beta}{L^*} n + \sum_{i=0}^{6} \lambda_i C_i \quad \ldots\ldots (4)$$

integrating

$$n = n_o \left\{ \frac{\beta}{\beta - \delta k} e^{\frac{\lambda \delta k}{\beta - \delta k} t} - \frac{\delta k}{\beta - \delta k} e^{-\frac{\beta - \delta k}{L^*}} \right\} \quad \ldots\ldots (5)$$

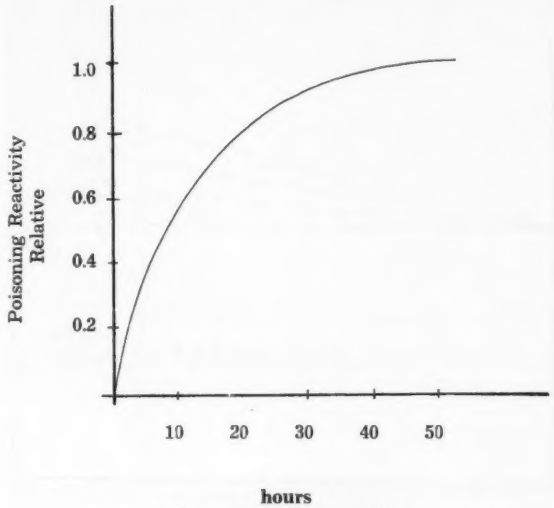
Substituting some typical values, $k = 0.003$, $L = 10^{-3}$ sec., $\beta = 0.0075$, and $t = 3$ seconds, [1] we see that equation (2) gives $n = 8{,}000\ n_o$ while equation (5) gives $n = 2.1 n_o$. If in equation (5) the first term on the right is considered the stable term and the second term is considered a transient, the stable period with delayed neutrons becomes

$$T = \frac{\beta - \delta k}{\lambda \delta k} \quad \ldots\ldots (6)$$

Again substituting the typical values as above, and comparing equations (3) and (6) we get a period of 0.33 seconds and 15 seconds respectively. This example shows that without delayed neutrons, control would be practically impossible. It is only with small multiplications and long periods that stable operation is possible with fluctuating loads.

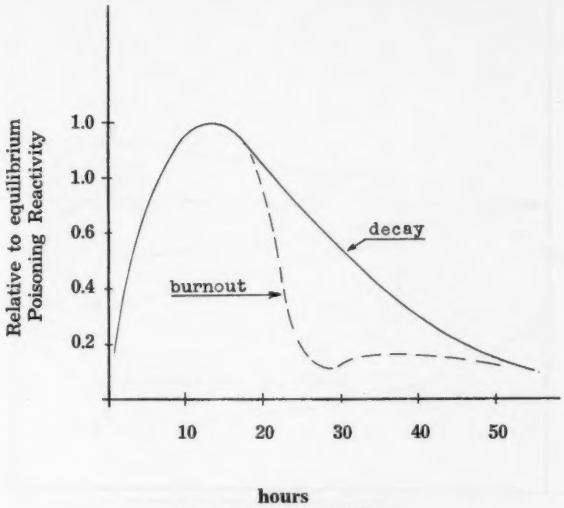
One of the primary functions of a control system is to prevent the multiplication factor, k, from becoming greater than 1.0075. 0.0075 is the fraction of delayed neutrons. Above this value, the reactor can sustain a chain reaction on prompt neutrons alone and the reactor will go onto a short period and run away. Such a condition is referred to a prompt critical.

The most advertised control feature of a pressurized water reactor is its negative temperature coefficient. In a pressurized water reactor, the water acts as both a coolant and a moderator. The majority of all fissions in a thermal reactor are caused by slow (thermal) neutrons. The purpose of the moderator is to slow the fast (high energy) neutrons down to thermal energies by billiard ball-like collisions between the neutrons and the hydrogen and oxygen nuclei of the water. However, as water is heated it becomes less dense and reduces the number of nuclei per unit volume, which reduces the number of collisions per unit time. Therefore, increased temper-



Xenon buildup, operation

Figure 1



Xenon buildup, shutdown

Figure 2

ature reduces reactivity since there are fewer thermal neutrons produced per unit time. This condition is referred to as a negative temperature coefficient.

Pressure changes cause a similar effect except that it is positive (i.e. increased pressure increases reactivity and vice versa). Because water is not very compressible and the pressure fluctuations are very small, the pressure effect is about one hundred times smaller than the temperature effect and is usually neglected.

A third important factor in reactor operation and control is the fission product poisoning. Certain fission products, notably xenon, and to a lesser extent samarium, have a large neutron absorption cross section which acts to reduce core reactivity. Xenon is formed, directly as a fission product and as a decay product of iodine (which is also a fission product) and is destroyed by neutron absorption and natural radioactive decay in accordance with the following equation. [3]

$$\frac{dx}{dt} = (\gamma_x \Sigma_f - \sigma_x x)\varphi + \lambda_I I - \lambda_x x \quad \ldots\ldots\ldots (7)$$

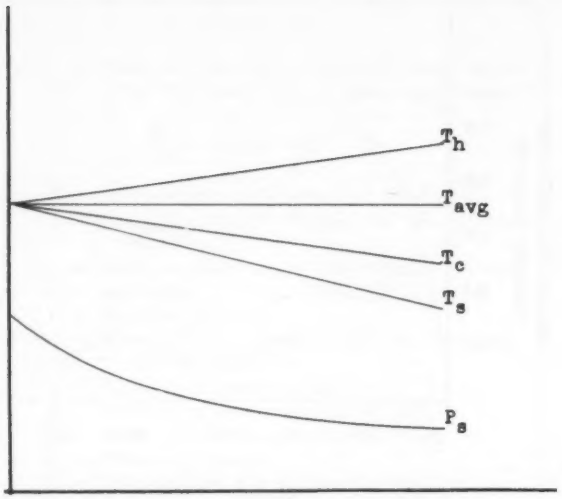
After approximately forty hours of operation the xenon reaches a steady state where the rate of formation equalizes that of destruction and will not cause any further disturbance to the system. However, after shutdown, because the iodine has a shorter half life than xenon, the xenon concentration increases, reaches a maximum approximately eleven hours after shutdown, and then decays. This will have a considerable effect on operation after a short shutdown and will be more fully discussed in a later section.

Ultimately it is the control rods which override all other influences on the reactor and give the operator positive control. In this paper, the rods will be considered in terms of reactivity. That is, a control rod is a device for inserting either positive or negative reactivity into the core. The rods are conveniently divided into three functional groups, shim rods, regulators, and safety rods. Shim rods adjust for long term transients in operation such as fission product poisoning and fuel depletion. Regulator rods adjust for variations in the thermal loading, while the safety rods provide the necessary negative reactivity to assure shutdown. The rods may perform any of the three functions except that the regulator rods are usually restricted to less than 0.0075 reactivity so that a control error will not permit prompt critical operation.

There are many modes of operation for a pressurized water reactor. The two limiting cases and some compromises shall be described.

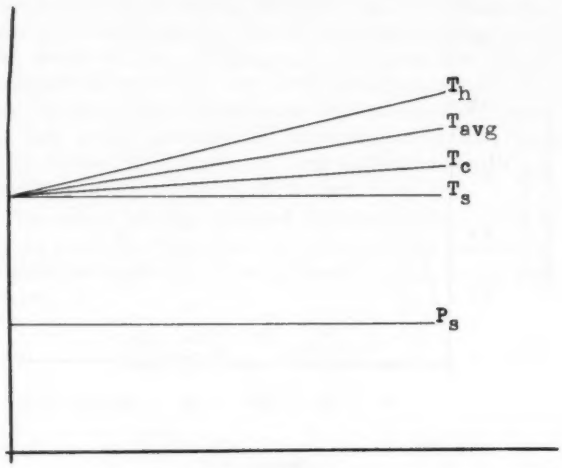
The mode most favorable to the reactor is a constant average temperature, T_{avg}, program. The negative temperature coefficient adjusts the power level to meet the throttle demands. When the throttle opens, the temperature, T_c, of the coolant returning to the reactor is decreased, this lowers T_{avg} and increases reactivity. The increased reactivity increases the coolant temperature T_h out of the reactor and returns T_{avg} to its initial value. The temperatures and pressures vary as shown in Figure 3.

The primary disadvantage of this program is the variable steam conditions, especially the decreasing pressure with increasing power. This pressure effect



Power Level

Figure 3



Power Level

Figure 4

requires special throttling devices and moisture separators.

The opposite extreme to the T_{avg} program is a constant steam temperature, T_s, program. This program is the most favorable to the steam cycle and permits optimization of the steam plant and the use of standard throttles and turbines. The disadvantage of this system is that control rod motion is required to offset the inherent T_{avg} program of the reactor. The temperatures vary as shown in Figure 4.

The above descriptions are for a constant flow of primary coolant. The flow may be altered in two ways, completely variable, and variable only in discrete steps. For a T_{avg} program the temperature variations would be as shown in Figures 5 and 6. There are two advantages to be gained by combining variable flow with a temperature program. For maximum efficiency it is desired to maintain T_{avg} as near to the maximum allowable T_h as possible. Variable flow permits a high T_{avg} with a wide range of power variation. Also, when operating at low power, the plant efficiency may be improved by reducing the coolant pumping rate and thus reducing the power required by the reactor.

The constant T_{avg} and T_s programs are the two limiting cases, one favors the reactor, and the other favors the steam cycle. Compromise programs such as a constant T_c or T_h program are also possible. The *Nautilus* operates on a constant T_c program while all subsequent plants have a T_{avg} program. A good compromise uses some program other than T_{avg} but has a slow control system. For slow throttle changes the reactor follows the designed program, but for rapid load changes, the reactor acts initially on a T_{avg} program and then slowly returns to the designed program as the control system takes command.

To show the effects of xenon poisoning on operation after a short shutdown, assume that the reactor is started up eleven hours after shutdown. Bringing the reactor to normal power will cause xenon burnout and will increase the slope of the xenon decay curve as shown in Figure 2. This rapid xenon poisoning removal puts reactivity into the core and unless the control rods are moved to insert negative reactivity into the core, the reactor will rapidly increase its power level. This poison burn-out requires constant rod motion until the steady state xenon concentration is reached. The rate of change of this xenon reactivity sets a minimum on the speed of the control rod motion.

An inventory of typical values of the variable reactivity in a reactor provides a summary of the preceding material and shows what net worth of reactivity is required of the control rods. [1]

Negative Temperature Coefficient	
room to operating temperature	—0.05
Peak xenon poisoning	—0.10
Fuel depletion	—0.03
Excess reactivity (for designed core life)	0.17
Required safe shutdown reactivity	
(in control rods)	—0.09

From this table it can be seen that for the cold, clean reactor the control rods must have an initial worth of at least 0.26 to overcome the excess reactivity and to provide the negative 0.09 shutdown reactivity. It is also shown that the designed core life is that point when the reactor can not be started hot at peak xenon poisoning. That is, with the control rods at

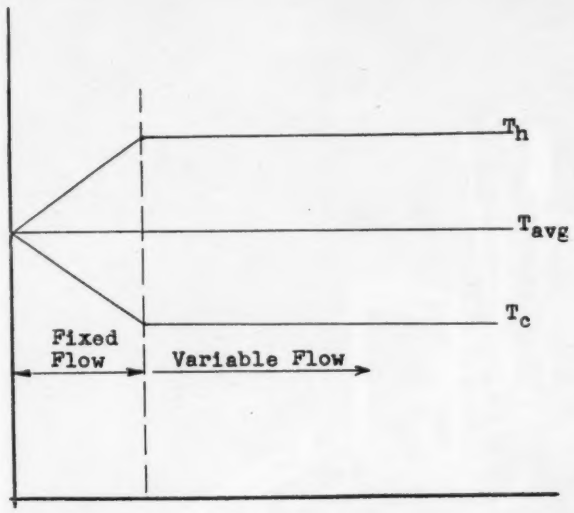


Figure 5

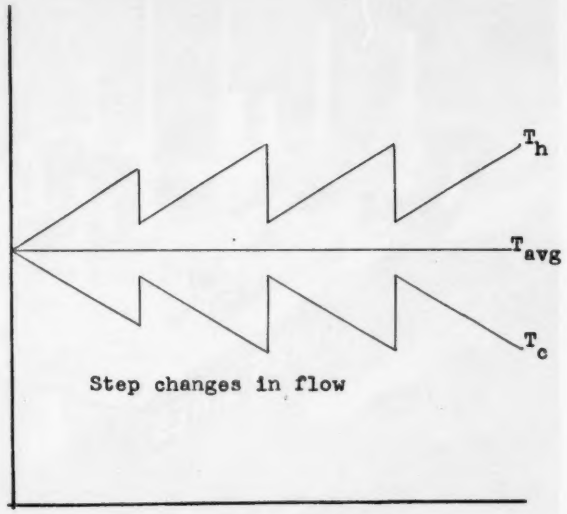


Figure 6

their extreme out position the 0.17 excess reactivity is insufficient to overcome the 0.18 negative reactivity caused by the peak xenon poisoning, negative temperature coefficient, and fuel depletion. Note however, that if the reactor is kept running or only cold starting is used, operational life can considerably exceed the designed core life.

The control rods themselves create problems. Their reactivity is not linear with their motion and each rod effects it neighbors in a manner peculiar to the individual core. The reactivity of the rod is linear with its motion only during the middle 40 percent of its travel due to the flux variations near the edges of the core. The speed of rod motion should be as slow as possible and yet sufficient to overcome such things as xenon burnout. It is a philosophy of control design that if nothing moves fast there can be no fast accidents.

It can be seen then, that a pressurized water reactor presently possesses two great advantages over other types of reactors. One, it has a relatively simple control system, especially when operated on a T_{avg} program. And two, not discussed here, is the convenience of water as a heat transfer medium. Since the reliability of a negative temperature coefficient is inherent, the pressurized water reactor is the best presently available for marine use where simplicity and reliability are paramount.

BIBLIOGRAPHY

1. Schultz, M. A. *Control of Nuclear Reactors and Power Plants.* McGraw-Hill Book Company, New York, 1955.
2. Glasstone, S. *Principles of Nuclear Reactor Engineering.* D. Van Nostrand Co., Inc., New York, 1955.
3. Glasstone, S. and Edlund, M. C. *The Elements of Nuclear Reactor Theory.* D. Van Nostrand Co., Inc., New York, 1952.
4. Kaplan, I. Course 22.21 Notes. Massachusetts Institute of Technology, 1958.

LYKES LINES USES 'BUFFALO' FANS

The SS James Lykes is the first to be completed of nine freighters now being built in accordance with the design of Gibbs and Cox, Naval Architects, the start of a half-billion dollar construction program calling for 53 new Lykes Brothers cargo vessels.

Each of these first nine ships will carry 26 'Buffalo' Hull Vent Fans, including special swing-out 'Buffalo' Axial Flow Fans for machinery space supply and exhaust, and high-pressure 'Buffalo' Centrifugal Air Conditioning Fans. (Accommodations for passengers, officers and crew will be air-conditioned). Other 'Buffalo' Fans include direct-connected Maritime Standard Centrifugals, as well as vee belt driven Maritime Centrifugals and Direct Connected Maritime Standard Propeller Fans.

Whatever your needs in fans, pumps or machine tools aboard ship, you can rely on 'Buffalo' for the utmost in trouble-free efficiency. Write us about your requirements. We will be glad to help you in every way possible.

MARINE DEPARTMENT: 711 Woodward Building • WASHINGTON 5, D. C.

"Buffalo"

BUFFALO FORGE COMPANY

Buffalo, New York

Canadian Blower & Forge Co., Ltd., Kitchener, Ont.

Buffalo air handling equipment to move, heat, cool, dehumidify and clean air and other gases.

Buffalo Centrifugal Pumps to handle most liquids and slurries under a variety of conditions.

Buffalo Machine Tools to drill, punch, shear, bend, slit, notch and cope for production or plant maintenance.

"TRANSACTIONS OF THE INSTITUTE OF MARINE ENGINEERS"

RECENT DEVELOPMENTS IN PUMP AUXILIARIES FOR SHIPS

ACKNOWLEDGMENT

Because of the length of this paper by T. McAlpine and I. S. Paterson, some illustrations and the corresponding text were omitted, without disturbing continuity nor omitting essentials. For the complete article and the comprehensive discussions, the reader is referred to "Transactions of The Institute of Marine Engineers" Volume 72, number 6, of June 1960 from which this is reprinted.

INTRODUCTION

In the period since the end of the Second World War considerable development in marine pumping auxiliaries has taken place. To deal comprehensively with all types of pumps currently in use would exceed the space limitations of this paper, and, rather than touch only briefly on all types, the authors have selected services wherein important developments have taken place, and they have dealt with these in more detail.

The material selected has been classified under the following subject headings:

Boiler feeding
Condenser circulation
Engine lubrication and cooling
General water services
Cargo pumping

General topics, which are not included in the above, or, though mentioned, have not been fully dealt with under these headings, are grouped together at the end of the paper.

Little or no reference has been made to earlier practice, with which it is assumed that readers are familiar.

BOILER FEEDING

Of the pumps that run continuously during the operation of a marine steam propulsion plant, one of the most vital is the boiler feed pump. Its reliability must be beyond question, and for a long time almost all attention was concentrated on this aspect.

During the last fifteen years there has been a demand for various other qualities—some of them conflicting—leading to a variety of designs for increased efficiency, reduced bulk, reduced floor space, and easy replacement.

The range of turbofeed pump designs described is very wide, including horizontal machines, vertical machines, direct drive turbines, geared turbines, single-stage pumps, multistage pumps and various alternative hydraulic balance arrangements; and it may be worth while to consider the limitations which influence a feed pump design.

Basis of Design

If the turbine has a single pressure stage, a high blade speed is necessary to give a good blade efficiency, and this can be obtained either with a small diameter wheel running at very high rotational speed, or with a large diameter wheel at a correspondingly lower rotational speed. Wheel stress is determined by peripheral speed, but blade stress depends also on the radius; a 10-inch diameter wheel at 15,000 rpm has the same peripheral speed as a 30-inch wheel at 5,000 rpm, but the blade stress is three times as high. If a two-row wheel can be run near its maximum blade efficiency there is no advantage to be gained by additional pressure stages having two-row wheels. Indeed, there is likely to be loss because of the increased windage due to a wheel with partial admission running in high pressure steam. To get any substantial improvement by multistaging it is necessary to go to single-row wheels and to use at least four or five stages. A multistage turbine is not so suitable as a single-stage turbine for quick starting from cold in emergency.

A high speed pump, that is to say a pump running at speeds above about 5,000 or 6,000 rpm, is usually less efficient than a pump running at lower speeds, and it requires a greater suction head, particularly with large capacity pumps. Centrifugal pumps are subject, in respect of efficiency and of suction head, to detailed differences in design, but, other things being equal, a multistage pump at lower speed is more efficient than a single-stage pump at high speed; and the suction head required varies approximately in direct proportion to the speed.

Also, although vertical feed pumps such as those illustrated are in successful operation, a horizontal feed pump is generally to be preferred from constructional design considerations.

Most of the pumps illustrated have automatic hydraulic balance. Others are partially balanced by opposed impellers with the residual thrust taken on thrust bearings. The hydraulic balance piston is a very powerful balancing device operating satisfactorily on a great many boiler feed pumps throughout the world, and it is difficult to see any advantage in the adoption of opposed impellers which require an external thrust bearing. The balance obtained by opposed impellers can be upset under cavitation conditions when some of the impellers are not completely full of water, and in such pumps the thrust bearing must be capable of taking a large portion of the unbalanced thrust of the machine.

High Efficiency Turbofeed Pump

Figures 1 and 2 show a modern high efficiency turbofeed pump, in which the pump is direct driven through a flexible coupling by a steam turbine. As compared with earlier designs, which usually had a continuous common shaft for pump and turbine, the adoption of a flexible coupling makes the critical speeds of the pump and turbine shafts independent. This permits the turbine to have a large and efficient wheel on a stiff shaft, while the pump shaft is relatively small in diameter. In accordance with widely adopted practice for land power stations, the pump—though not the turbine—runs through its first critical speed. The small shaft diameter allows a small impeller diameter with more stages and this gives a higher pump efficiency.

These figures show sections of the pump and turbine ends respectively. The pump thrust is automatically balanced by the hydraulic balance piston, and the turbine thrust is taken on a thrust bearing. The pump end shown in Figure 1 is of the barrel casing type which is used for suction temperatures above about 250 deg F. For lower temperatures the ring section type pump is used.

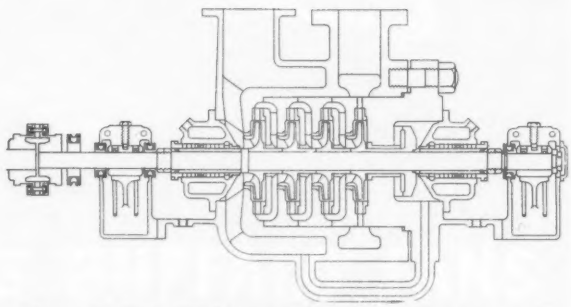


Figure 1. High Efficiency turbofeed pumps: water end.

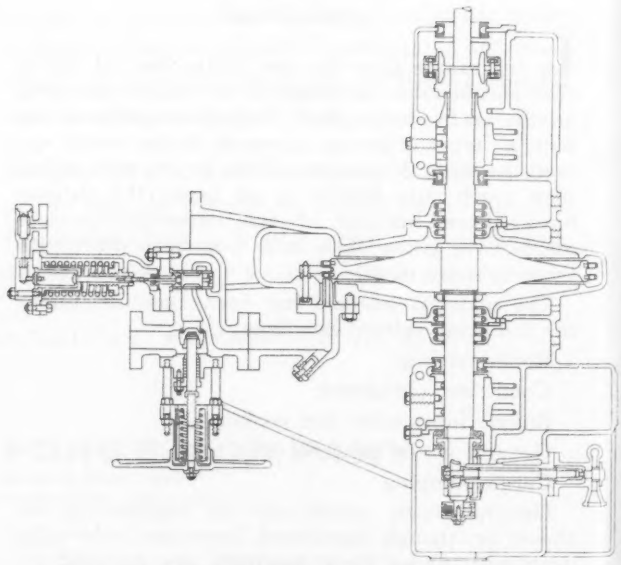


Figure 2. High efficiency turbofeed pump: steam end.

The design gives a good pump efficiency, and a turbine efficiency which is good in relation to the power developed and the operating conditions. The pump speed is selected at about 5,000 rpm to give high efficiency with a comparatively stiff shaft and to operate with a moderate suction head. Having decided on pump speed, turbine blade speed depends on the diameter of wheel; and if a very large wheel is chosen, the windage losses, with partial admission, in a machine exhausting to a back pressure, may more than offset any further gain in blade efficiency. This can also apply to pressure compounding. Figure 3 shows performance curves for a machine of this type.

One way of increasing the efficiency is to fit gearing between the pump and turbine so that a small diameter, high speed turbine can be run at about 11,000 or 12,000 rpm.

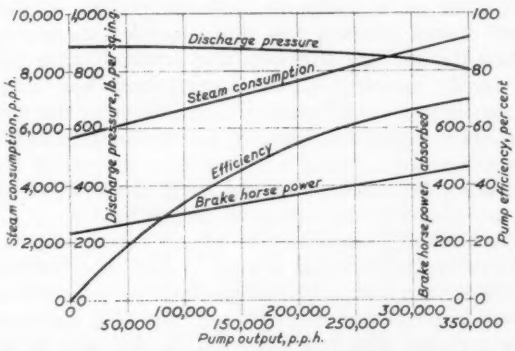


Figure 3. Performance curves for high efficiency turbofeed pump.

Steam: 600lb./sq. in. gauge; 850 deg. F.
Exhaust: 15lb./sq. in. gauge
Suction: 45lb./sq in. gauge; 250 deg. F.

Electrically Driven Boiler Feed Pumps

Another way of increasing the overall efficiency is to drive the pump by an electric motor. The pump end is similar to the high efficiency turbofeed pump, but for a-c supply it would run at about 3,600 rpm and would have more stages. The efficiency of the pump end is about the same as the turbofeed pump, but the larger multistage turbine of the turbogenerator will usually have a higher efficiency than the single-stage turbine or a turbofeed pump, even after allowing for losses in gearing, alternator and motor. Electrofeeders are almost universally used in land power stations except for extremely large sets; but when they are installed in ships the problems of starting currents must be kept in mind. When direct current is used, starting is simpler, but high speed motors cannot be obtained except for low powers and it is usually necessary to introduce gearing between the pump and motor. Figure 4 shows performance curves for an electrofeeder for comparison with Figure 3, which applies to a turbofeed pump operating under the same conditions.

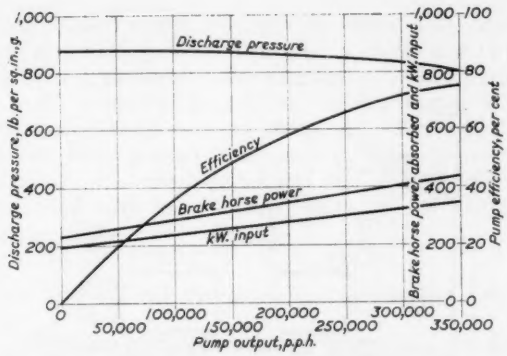


Figure 4. Performance curves for electrofeeder.
Suction: 45lb./sq. in. gauge; 250 deg. F.

Other Types of Feed Pump Drive

The problem of starting currents and the losses of alternator and motor can be avoided by driving the pump direct from a gear shaft of the alternator. This is probably the most efficient way of driving a feed pump—unless it is driven from the main engine—although it is not quite so flexible as an independent drive. Internal clearances must be large enough to allow the pump to run dry for a few minutes, in case at any time it should lose suction, and this reduces the efficiency. If a suitable clutch can be developed this drive will be very attractive.

Another method—largely a combination of these two methods—is to connect the electrofeeder motor electrically to the alternator before the alternator is started, and bring the two up to speed together. There would of course be a switch but it would be used only for breaking the circuit in emergency, as for instance on loss of pump suction.

This method has been used for a long time as a works practice in the testing of large electrofeeders. The electrical losses must be taken into account but these become less serious in large machines where the problem of starting an electrofeeder in the ordinary way would be particularly formidable.

Turbofeed Pump with Water Lubricated Bearings

All the feed pumps so far described concentrate primarily on efficiency. If one is prepared to sacrifice a little in this respect, the very compact design illustrated in Figure 5 is very attractive.

This pump has water lubricated bearings making use of new materials which are now available, thus eliminating turbine and pump glands and enabling a short stiff shaft to be used with overhung turbine wheel and overhung pump impeller. A speed of about 10,000 rpm enables a high turbine efficiency to be obtained with a relatively small wheel. The pump is provided with a diffuser to give high efficiency and to minimize side thrust. The overall efficiency of the machine is only a little lower than that of the much larger pumps described above. Because of its high speed the pump requires a

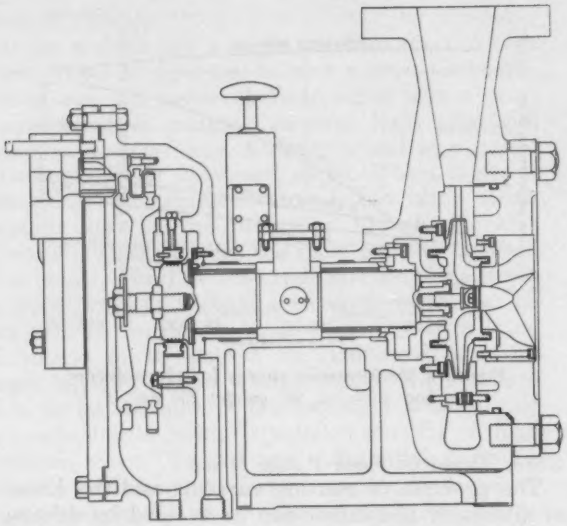


Figure 5. Turbofeed pump with water lubricated bearings.

greater suction head from a high level deaerator. There is also no difficulty with low level deaerator installations as these have a deaerator extraction pump. This design of pump has been tested extensively and will soon be running in a number of ships.

Comparative Particulars of Turbofeed Pumps

Table I gives an approximate comparison of these various types of turbofeed pump, including the well known standard design, which is not described in this paper, in relation to the high efficiency turbofeed pump which is taken as the basis of comparison.

TABLE I

Turbofeed pump type	Figure number	Relative percentage	
		Steam consumption	Weight
High efficiency	1, 2	100	100
Geared	Not illustrated	93	100
Water lubricated	5	120	25
Standard multistage	Not illustrated	140	40

Recent Naval Practice

During the past fifteen years or so, the British Admiralty have installed turbofeed pumps of widely varying types. The first major departure from previously accepted practice is in the *Daring* Class Destroyers where a pump end of conventional design is driven by a turbine having two, two-row wheels. This reduces the turbine diameter, but it is not possible by this means to get a turbine efficiency greater than can be obtained with a single large diameter two-row wheel; and the windage losses are increased.

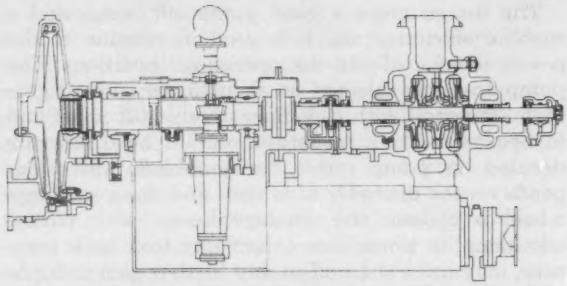


Figure 6. Turbofeed pump for *Whitby* Class frigates.

The feed pump in the *Whitby* Class Frigates, Figure 6, is a much greater step from tradition. A single two-row overhung wheel drives, through a flexible coupling, a two-stage pump having three impellers arranged to give hydraulic balance without the need of a hydraulic balance piston. A very small thrust bearing was fitted to take up any residual thrust; but although this worked quite well on steady running, it was soon found that inadequate suction could cause unequal flow to the two-first-stage impellers, causing one to cavitate before the other, and giving a heavy end thrust. It was necessary to increase considerably the size of the thrust bearings to overcome this difficulty.

Blackwood Class Frigates have a feed pump still further from tradition, Figure 7. This is a vertical machine in which a four-stage feed pump with opposed impellers is mounted on top of a gearcase. The turbine, which is mounted on the side of the gearcase, has a 10-inch diameter wheel running at 16,000 rpm. The four-stage pump has the first two impellers facing downwards and the second two impellers facing upwards, so that the pump is in hydraulic balance. The pump thrust bearing is sufficiently large to take the unbalanced thrust of two impellers, a condition which arises if the pump is deprived of suction. This occurs when the pump trip speed is being tested.

The prototype YEAD I machinery installation included a vertical turbofeed pump with the turbine and gear case on top and the pump below. This gives a neater design, but the baseplate—constructed to withstand shock—almost entirely encloses the pump end of the machine, and access is difficult. This design was based on the understanding that the pump need never be repaired on board ship, but would be replaced by a spare pump.

Later Admiralty designs have reverted in some respects to traditional practice, while taking advantage of much that has been learned from the designs which have been described. Recent feed pumps are horizontal. They occupy a little more floor space than vertical machines but are much easier of access, as well as being simpler in regard to the arrangements for oil drainage from bearings. A horizontal machine has the great advantage that

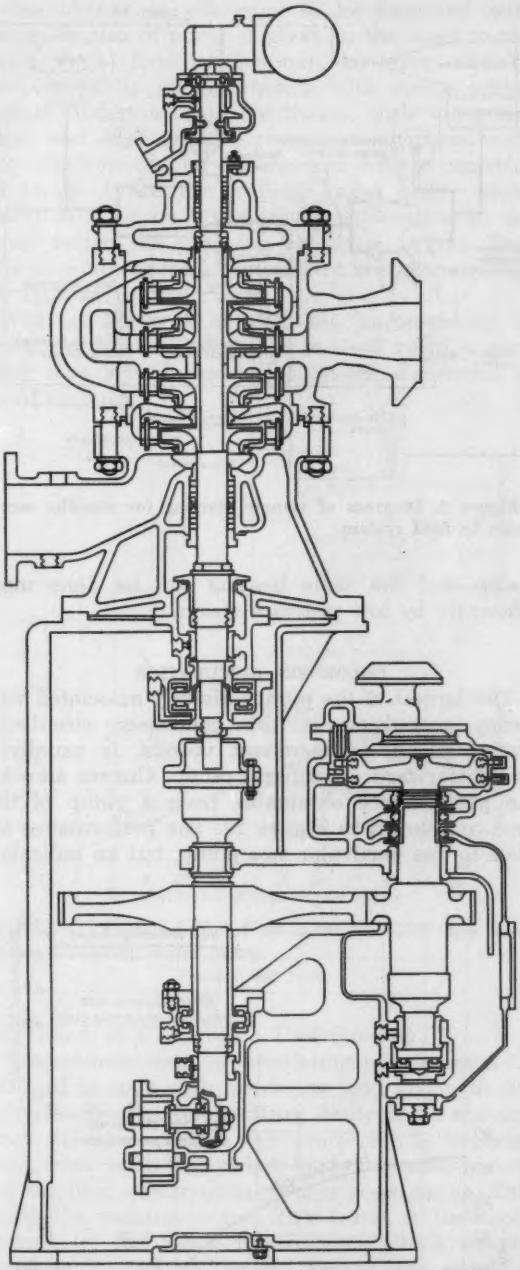


Figure 7. Vertical turbofeed pump for *Blackwood* Class frigates.

the base forms a convenient oil sump, and that oil from the bearings drains naturally to it. These later pumps have reverted to hydraulic balance piston instead of opposed impellers.

Mechanical Seals

The Admiralty are at present leading the way in this country in the adoption of mechanical seals for boiler feed pumps. Most of their latest pumps have stuffing boxes which incorporate these seals and which also have provision to take a gland and two rings of soft packing if the mechanical seal should fail. In the course of time it may be found that this precaution is not necessary; but until more experience has been gained it is wise to keep in mind that failure of a mechanical seal can be more difficult to deal with in emergency than failure of soft packings.

Design of the Feed Pump in Relation to the Feed System

In considering the efficiency of boiler feed pumps it is worth while remembering that power may be wasted in boiler feeding, even with a very efficient pump. All centrifugal pumps have a peak efficiency and it is desirable to operate normally near this point. If the maximum output is greatly in excess of the normal output the pump will normally work much below its best efficiency. The maximum output can be arranged beyond the best efficiency point of the pump, but pressure falls steeply in this region. The pump must therefore run faster at overload than at normal load and, with a turbine drive, this may probably entail loss of turbine efficiency at normal load. If there is a big difference between normal and maximum feed requirements, it is probably best to select the pump for normal load, plus a margin of say 20 per cent to cover fluctuations in the feeding rate, and to use two pumps for overload. The second pump could easily be started by remote control from the maneuvering platform or from the boiler room. There would probably be a total of three pumps, one running, one ready for starting in parallel by remote control, and one standby for emergency.

There are many cases where an arrangement of this kind could give greater savings than are likely to be obtained by any further improvements in the efficiency of the boiler feed pump or its driver. In Figure 8 steam consumption is shown for a

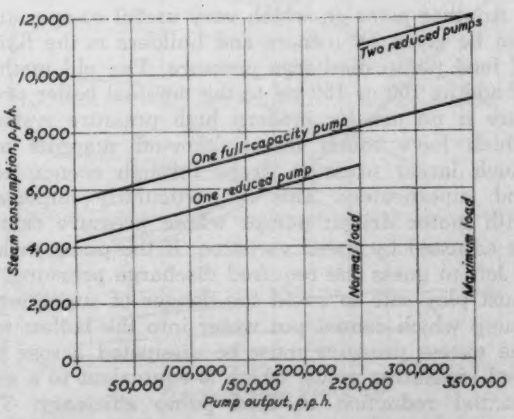


Figure 8. Saving in steam with smaller pump.

pump capable of normal load—taken at about 70 per cent of maximum load—and for a pump which is capable of the maximum load. If the smaller pump is selected, two will be required at full load and will take more steam under this condition. Co-operation of the owners is required, because the pump maker will not be happy about installing a pump incapable of feeding the boilers at their maximum evaporation, unless he is assured by the owners that a second pump will be started immediately it is required.

In many vessels, where there is a wide difference between maximum evaporation and normal evaporation, maximum steam may be required at short notice for full astern power.

All of the additional auxiliaries required for maneuvering can easily be started, and all necessary bypass valves, etc., can be opened by an arrangement such as that shown in Figure 9. Water under pressure from the main feed line is taken through a restriction orifice to a piston which holds the steam valve of the standby feed pump closed. This pressure also holds in the closed position a bypass valve on each of the feed pumps and a recirculating valve from the feed line on the outlet side of the air ejector leading back to the condenser. It also holds in the open position the starting switch on the standby condenser extraction pump. If the remote control valve shown in the diagram is opened, this releases pressure from the steam valve, bypass valve, recirculating valve and pressure switch, thus starting the standby extraction pump and standby feed pump and opening the feed pump bypass valves and the condenser recirculating valve. The remote control valve and all of the control piping would probably be ½-inch bore and the valve could be opened in a few seconds whenever any signal is received for maneuvering. The remote control valve could be arranged at the control platform. If desired, an additional valve could be located in the boiler room and opening either of these valves would start the standby pumps and open the bypass connections.

Another point on which very useful co-operation can be given by owners and builders is the fixing of feed pump discharge pressure. The old method of adding 100 or 150 psi to the nominal boiler pressure is no use for modern high pressure systems which have much larger blow-off margins and much larger pressure drops through economizers and superheaters. This is particularly important with motor driven pumps whose pressure cannot be adjusted by speed variation. If the pump maker is left to guess the required discharge pressure, he must play safe to avoid the danger of supplying a pump which cannot put water into the boiler; and the excess pressure must be dissipated across the feed regulating valve, which is equivalent to a substantial reduction in feed pump efficiency. The energy is not lost—it reappears as heat in the feed

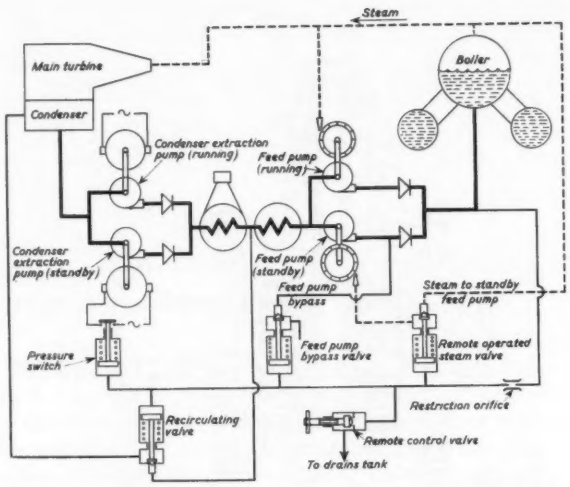


Figure 9. Diagram of remote starting for standby auxiliaries in feed system.

water—but the same heating can be done more efficiently by low pressure steam.

CONDENSER CIRCULATION

The largest of the pumps directly associated with steam propulsion is the condenser circulating pump, which, in merchant vessels, is usually a straightforward centrifugal pump. Curves showing the performance obtainable from a pump of this type are shown in Figure 10. The performance applies to one particular size pump, but an indication

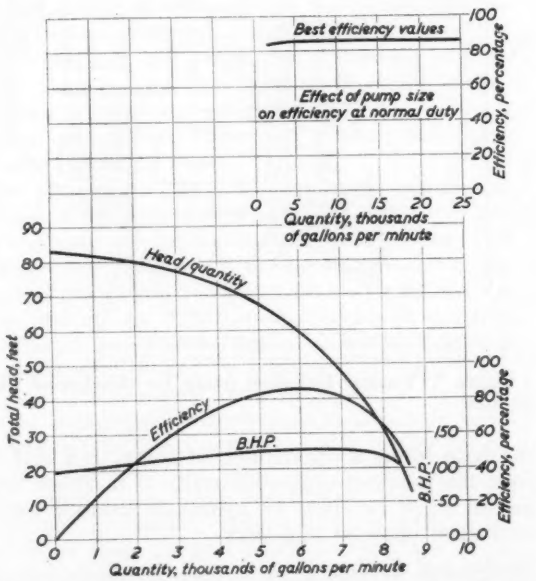


Figure 10. Performance of 20-in. centrifugal condenser circulating water pump.
Speed: 960 rpm.

of the change in efficiency to be expected with change in size of pump is given in the inset to the graph. Axial flow pumps may, however, also be used, generally in conjunction with scoops which operate under cruising conditions, with the pump idling and offering little resistance compared with that which would be experienced with a centrifugal pump. Since the trailing losses under scoop operation must be taken into consideration in the pump design the pumping efficiency suffers. Performance curves for a typical unit are given in Figure 11.

With either type of unit the pump design is straightforward and does not in itself call for comment; it may be driven by a.c. motor, d.c. motor or steam turbine.

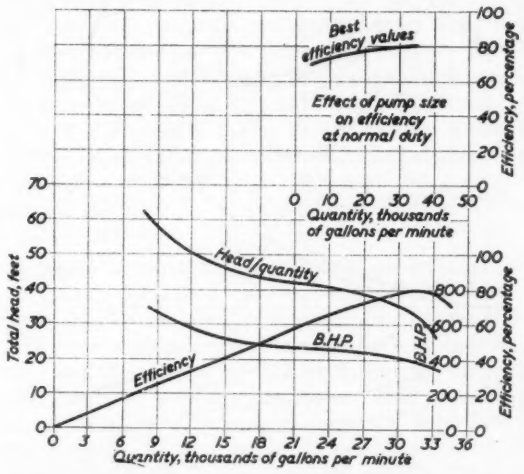


Figure 11. Performance of 40-in./36-in. axial flow condenser circulating water pump.
Speed: 640 rpm.

Prevention of Condensate Undercooling

A condenser and its circulating pumps must be designed to cope with maximum load and with the highest sea water temperature likely to be encountered. Because of this the condenser is oversurfaced when operating at low load or in cold waters, and the flow of circulating water is excessive. This causes the vacuum to rise. This is not, in itself, objectionable; but, since the vacuum which can be raised is limited by the air ejector, the result is undercooling of the condensate, as discussed in more detail later. This increases the oxygen content of the condensate as well as causing a thermal loss and increasing the wetness of the steam in the last stages of the turbine.

Variation of Circulating Water Flow Rate

The conventional approach to this problem of undercooling is to vary the circulating pump by some means, and a brief comparison of the relative merits, from pumping considerations, of the existing methods of obtaining output variation is therefore introduced at this stage, with reference to an all-frictional system resistance characteristic of the type applicable to condenser circulating duties, where resistance varies approximately as the square of the quantity.

When speed variation is possible, as in the case of d-c motor or turbine drive, this presents a simple and efficient means of obtaining variable flow rates. The pump can be selected to operate at maximum efficiency under normal conditions and, by altering the speed, any other flow rate can be obtained, still maintaining operation at or near maximum efficiency. This results in minimum wear and tear on the pump and minimum horse power requirements.

Conditions of operation are readily appreciated by reference to the graph shown in Figure 12, which, in common with subsequent graphs in this section, relates changes in the pump variable to the values obtained at the best efficiency point. (Where applicable in these graphs the effect on operating conditions is traced out for reduced flow rates of 80 per cent and 60 per cent of the normal duty value. The effect of reduction to still lower values can also be easily estimated.)

With increased use of a-c supply the facility of speed variation is not so simply obtained and involves a costly power unit. Consequently recourse to one of the following methods applicable to the pump is usually made, with either a single fixed speed or a two-speed motor.

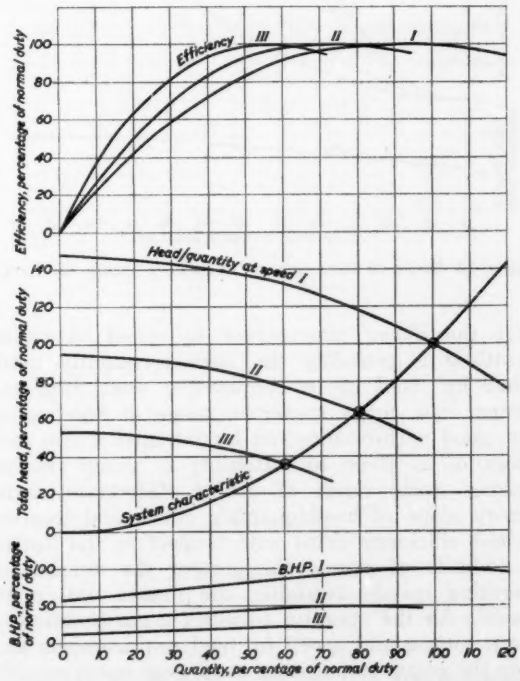


Figure 12. Reduced flow rate by speed variation.

a) Throttling of the pump discharge. This in effect increases the system resistance and the operating point can be adjusted to give any required throughflow, at the expense of loss in efficiency through additional energy dissipation in the pump, as well as in the restriction, as indicated in Figure 13.

b) Single-speed pump with simple bypass from the pump discharge back to the suction. This method is to be preferred to throttling where considerable reduction in flow is required since the pump is not subjected to undue wear and tear. A recent development based on the bypass principle is discussed more fully later in this section.

c) Two small pumps arranged for single or parallel operation. This is very limited in scope, and results in operation well removed from the design point at the reduced flow condition, unless throttling of the single pump is also employed.

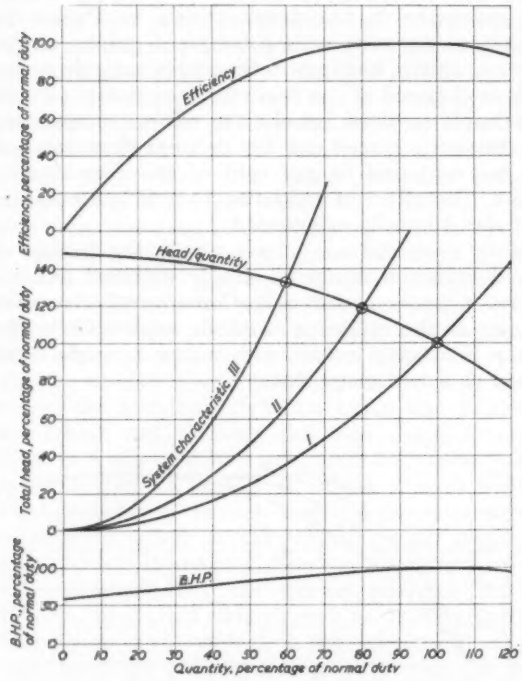


Figure 13. Reduced flow rate by throttling pump discharge.

Of the above alternatives to speed variation, throttling is probably the most frequently used, either by itself or in conjunction with duplicate pumps; and, for a moderate range of flow variation, good performance can be obtained if due consideration is given to suitability of pump characteristics—wide range of useful efficiencies, satisfactory slope of head/quantity curve and location of best efficiency point with respect to the duties. In addition of course the greater the number of operating speeds available, the nearer will it be possible for the operator to select a combination of pump setting and speed to meet requirements and keep the pump functioning at or near optimum efficiency. As regards the actual power consumed at reduced flow rates, this is also governed by the horse power characteristic of the pump (falling towards zero flow for a centrifugal, rising for an axial flow) and may affect the choice of whether to throttle or bypass or use a combination of both.

When the axial type of pump is used there is the additional possibility of obtaining variable output by alteration of the impeller blade angle. The general effect is shown in Figure 14, from which it will

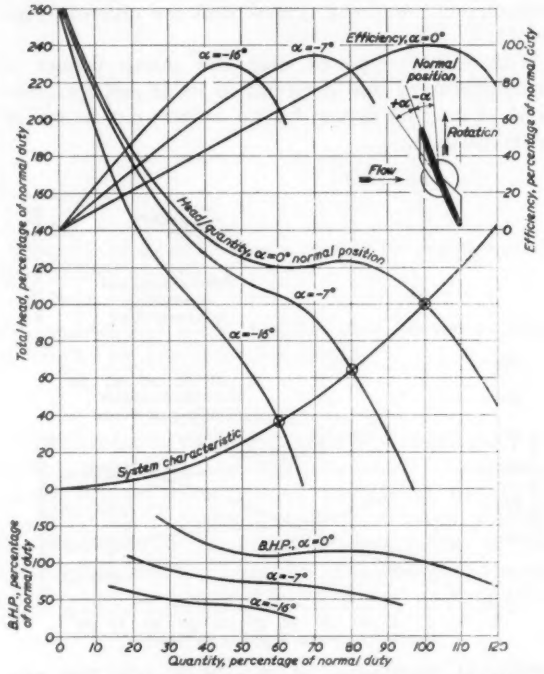


Figure 14. Reduced flow rate by variation of axial flow pump impeller blade angle.

be seen that there is a tendency to move well away from the best efficiency point, even at moderately reduced flows; and while this can be corrected by throttling, the bhp characteristic of the pump detracts from the benefit of this practice. It is of course a matter of preselection of blade setting, maximum efficiency and their disposition with respect to normal and reduced operating conditions, to obtain the best overall results for any particular application. Since, to obtain the adjustable blade feature, a certain amount of mechanism must be housed in the impeller hub and means for controlling it from outside provided, it is generally considered worth while only in the larger sizes of pump and where the conditions of operation are such that considerable benefit would result.

ENGINE LUBRICATION AND COOLING

Lubricating Oil Pumps—Tank Type Pumps

There has been a move in the last few years, initiated by the British Admiralty, to adopt cen-

trifugal lubricating oil pump units of the vertical type, with the pump suspended in the oil tank, immersed in the oil, in preference to positive displacement type pumps located above the tank.

The upper limit of capacity of these centrifugal tank type pumps is well above present marine requirements, but below 200 to 250 gpm efficiency considerations have resulted in a tendency to retain the normal floor mounted positive rotary pump. The fact that small positive displacement pumps have a higher efficiency than the corresponding centrifugal type, has however led, more recently, to the extension of the tank type design to positive displacement pumps for small capacity lubricating oil duties, and others where circumstances favor the positive design. These pumps share many of the advantages (enumerated later) of the centrifugal tank type and, in addition, benefit over their floor mounted counterparts in that noise due to air entrainment and cavitation is less prevalent since the rotors operate below the oil level. Advantage of this fact is normally taken to use higher operating speeds. The performance of the single-stage and two-stage centrifugal tank type, and the gear tank type pumps may be assessed from Figures 15 and 16 respectively.

A typical section of a single-stage centrifugal tank type pump designed for lubricating oil duty is shown in Figure 17. The twin-volute discharge arrangement reduces side thrust to a satisfactory level, and the special suction inlet, giving controlled inflow to the impeller, together with small discharge to suction injection holes suitably located with respect to the impeller eye, safeguard the pump against air locking when handling heavily

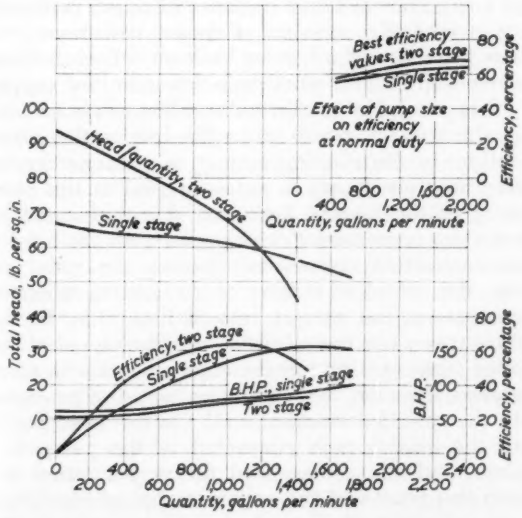


Figure 15. Performance of 12-in. single-stage/10-in. two-stage centrifugal tank type lubricating oil pumps.
Speed: 1,760 rpm. Hot oil

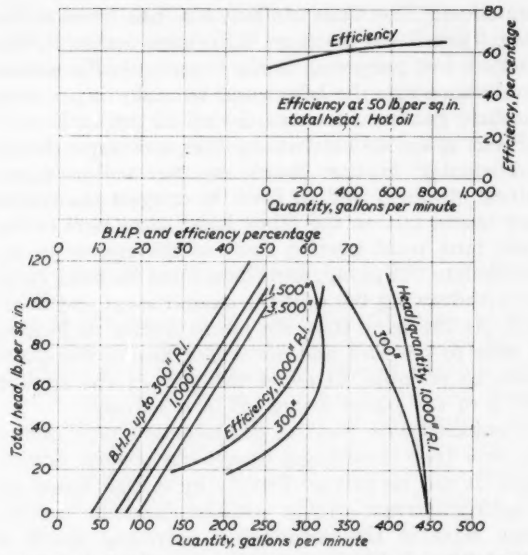


Figure 16. Performance of 6-in. gear tank type lubricating oil pump.
Speed: 1,300 rpm.

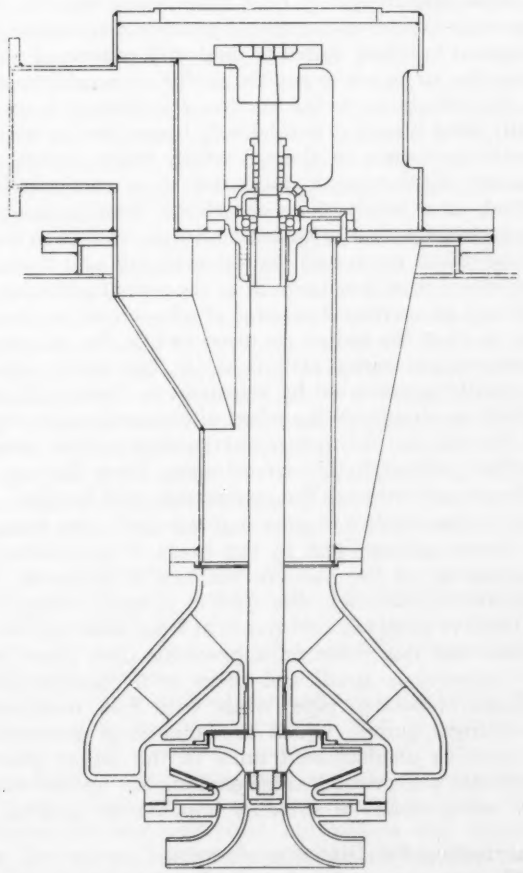


Figure 17. Single-stage centrifugal tank type lubricating oil pump.

aerated oil. The shaft stuffing box has little to do, since there is no pressure difference across it, but it serves two purposes; firstly it prevents the escape of oil vapor into the bilges and secondly it prevents moisture gaining access to the oil in the tank.

From space considerations the tank type design is attractive in that there are no suction pipes, valves, strainers and so forth to congest the under floor space, but on the other hand some part of the drain tank must project clear of the engine to accommodate the pump, and there must be head room for withdrawing the unit for examination and overhaul. At the same time the pump should be located as near to the fore and aft center line of the drain tanks as possible, to avoid the risk of the suction orifice of the pump losing oil in a seaway.

Compared with positive displacement type pumps the tank type centrifugal design has several advantages. It can be driven directly by a high speed alternating current motor without capacity restrictions, whereas the permissible operating speed of the positive displacement type, pumping an incompressible fluid, decreases as the capacity rises; it is silent in operation (as mentioned above, even the positive gear design of tank type pump benefits in this respect over conventional positive displacement units); it is better suited to deal with entrained air, since the air is not expanded under a vacuum such as that obtaining in the suction chamber of a normally sited pump; it is relatively insensitive to accidental inclusions in the oil which might wreck a positive displacement unit; and it is particularly suited, as a result of its centrifugal head/quantity characteristic, to lubricating oil duties, in that as the temperature rises, and the oil viscosity and therefore the system resistance falls, the centrifugal pump delivers an increased amount of oil—which in practice is what the engine requires—while the positive pump output varies little if at all. The latter point is readily appreciated by reference to Figure 18, in which for simplicity the effect of change in viscosity of the oil on the pump characteristics has been omitted, although this would again favor the centrifugal and enhance the comparison still further.

It is also worthy of note that the tank type pump is always primed and in the event of momentary uncovering of the suction, the loss of pressure is restored immediately the suction is again covered. A positive displacement pump at floor level will reprime, but this taken an appreciable time since its air capacity is small and there is a considerable volume of suction pipe; while with floor mounted centrifugal pumps, which are sometimes preferred to positive displacement units in the larger sizes, elaborate self-priming arrangements are needed and also some means of avoiding impeller air locking.

Lubricating Oil Discharge Systems

The pressure required at the lubricating oil pump to circulate oil through the lubrication system of either steam or Diesel machinery depends on the quantity of oil to be circulated and on the frictional resistance of the system. The latter includes filters, coolers, control valves, pipes, pistons (and the supply and return connections) when oil cooled, bearings, sprayers and so on, and it is not surprising, therefore, that, despite the greater attention now being given to the hydraulic design of piping systems and the fuller friction data available, the pressure which is registered at the pump gauge, and which is a property of the system, not of the pump, is seldom precisely the figure specified by the shipbuilder when ordering the pump.

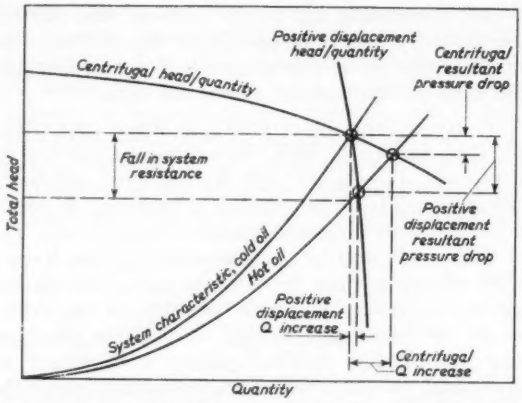


Figure 18. Comparison of centrifugal and positive displacement pump characteristics with respect to lubricating oil duties.

Although this anomaly is by no means a recent development and is becoming more widely appreciated and steps taken to reduce the disparity, recent alternative developments in lubricating oil systems still lead, on occasion, to pressure gauge readings being regarded as a measure of pump performance instead of a measure of system resistance.

The provision of a header tank on a branch from the main oil circuit, whereby a few minutes' supply of oil is available (sufficient to allow time to connect the standby pump on to the line in the event of failure of the running pump), may cause unnecessary worries if care is not exercised in the positioning of the header tank and the assessment of the system resistance. For example, with the header tank connection immediately before the main engines, the actual resistance of the system when in operation, at the correct rate of flow, may be insufficient to raise the oil to the overflow level of the header tank, resulting in the emergency alarm ringing even although the machinery is being provided with the specified amount of oil. On the other hand, with the header tank connected to the pump discharge, and the coolers and filters positioned between this point and the engine, a choked filter may cause starvation of oil to the machinery with ample overflow from the header tank and no emergency alarm. The effect of the system resistance would in

the first case cause a low pump discharge gauge reading, in the second a high reading.

When the header tank is fitted in the main oil circuit and handles the full flow quantity, the pump discharges (usually through the coolers and filters) to the tank at a given flow rate and the tank in turn supplies the main engines. The pump, in this case therefore, is only concerned with the supply of the specified flow rate to the tank, and the actual operating level in the tank at this rate, and the supply of oil to the engine, is governed by the height of the header tank in relation to the resistance to the passage of oil afforded by the engine.

Diesel Engine Forced Lubrication and Cooling Plant

In recent years there has been a steady tendency to increase the horse power obtainable from a given size and weight of main Diesel engine, involving a corresponding increase in the amount of heat to be removed from jackets, piston interiors and from the various bearings. There has also been an increased tendency to use oil instead of water for piston cooling, partly to avoid corrosion troubles and partly to overcome the difficulty of avoiding contamination of the oil in the crankcase due to leakage.

To deal with this additional heat, considerable increases in the amount of cooling oil to be circulated have become necessary without, in general, any corresponding increases in cooling oil passage areas, pipe or drain tank sizes.

One result is that the liquid in circulation spends less and less time in the drain tank. This is particularly serious in the case of oil since it inevitably becomes charged with air in the course of its journey through the engine to the drain tank, where the much reduced time available makes it impossible for the smaller air bubbles to reach the free surface, and the equilibrium proportion of air to oil becomes high. It must also be kept in mind that the oil can only return to the drain tank by gravity and height is severely limited by the need to place the main engine low in the ship. Careful attention must therefore be given to the design of the drain tank interior—baffling, passages in the frame and girder plates, relative location of crankcase drain and pump suctions, etc.—since what was satisfactory say ten years ago may be inadequate for the more demanding conditions today. Scale model tests, whereby different designs may be compared and an indication of conditions likely to be experienced in practice obtained, can be of great assistance in this respect. The use of anti-frothing additives in the oil may also prove of considerable benefit.

Another result is that the size of the oil pumps is steadily increasing, and, in the case of positive displacement type oil pumps, is tending to yield large and clumsy units which are awkward to overhaul, thus encouraging the use of centrifugal pumps.

Jacket and Piston Cooling Fresh Water Pumps

Tank type centrifugal pumps are being given consideration by some shipowners for this duty in preference to the ordinary type of self-priming centrifugal pump, the advantages of simplicity, lack of need for priming fittings and reduction of piping, etc., being already described under "Lubricating Oil Pumps."

Geared Turbine Forced Lubrication and Sprayer Pumps

As in the case of oil engines, advances, in this instance in turbine and gearing design, have led to increases in power output of geared turbine propulsion sets for a given size of machine and hence to an increase in the amount of lubrication and sprayer oil required. Reduction gearing causes heavy aeration of the oil and consequently careful design of the drain tank is again of paramount importance.

GENERAL WATER SERVICES

For general service duties such as ballast, fire, bilge, etc., there have been no outstanding developments in pump design of recent years, the majority of ships employing the compact vertical spindle centrifugal pump unit with electric driving motor mounted directly on top. This type occupies little floor space and is usually designed so that the front cover and rotating element of the pump may be removed without disturbing pipe joints or motor alignment.

A typical modern vertical centrifugual pump suitable for duties which do not require a self-priming ability is shown in section in Figure 19, while performance curves applicable to this design are given in Figure 20. The pump shown is a single-stage unit with single-entry impeller and serves to illustrate the now automatically accepted features of renewable impeller clearance rings in way of impeller bearing strips, stuffing box suitable for conventional packing, with or without grease or water service and with shaft sleeved in way of packing, or alternatively convertible to use of mechanical seals.

Self-priming Arrangements

Where the duty necessitates the pump operating with a suction lift, and a foot valve on the suction line is inadequate, some means of self-priming must also be provided.

The location of the air pump with respect to the water pump and driving motor may of course be varied, and different manufacturers have their standard arrangements, or a separate air pump may be used in a centralized exhausting system. The choice for any particular application will depend on the nature of the duty or duties involved and on the importance of accessibility, ease of maintenance, etc.

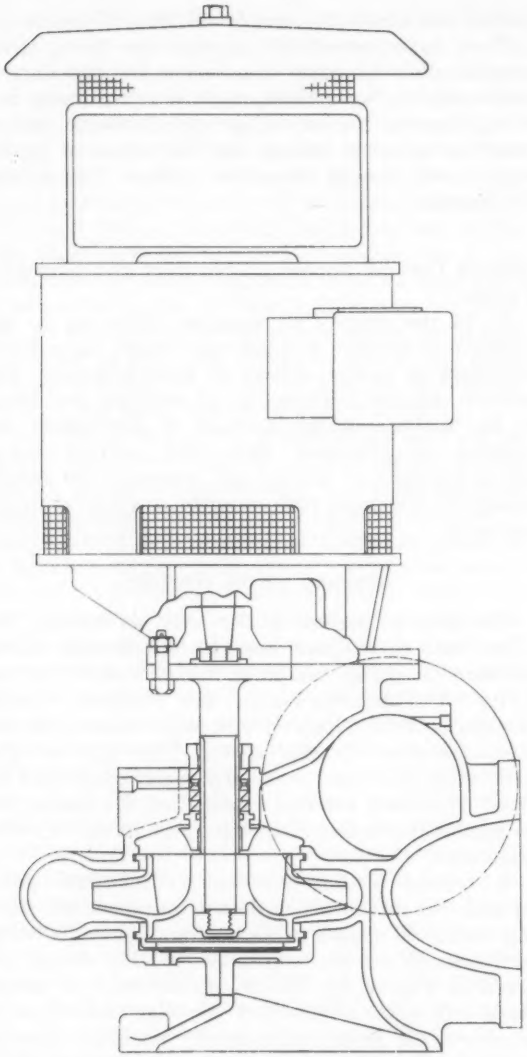


Figure 19. Single-stage centrifugal non-self-priming unit.

Separate Pumps for Incompatible Duties

While on the subject of bilge duties it seems appropriate to broach the question of multiple duty pumps.

At any particular speed a centrifugal pump can only operate at maximum efficiency at one point, the duty point for which it is designed (commonly referred to as the normal duty or best efficiency point on the pump characteristics). As the operating conditions move away from this point, conditions in the pump become more turbulent and more horse power is used "inefficiently" in creating turbulence and, in effect, tending to destroy the casing and impeller by cavitation and scour erosion. From the point of view of wear and tear on the pump it is therefore bad policy to install a pump to function

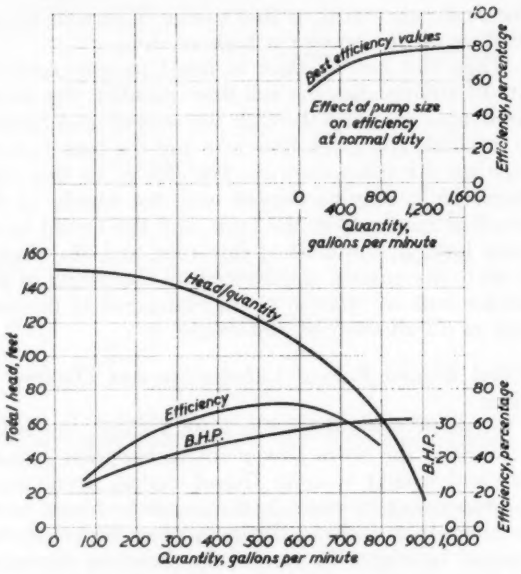


Figure 20. Performance of 5-in. centrifugal general water service pump.

Speed: 1,600 rpm.

on more than one duty, particularly with the advent of fixed speed a-c motor drive in place of the more versatile variable speed d-c motors.

One of the most common examples of use of a pump for double duties is fire and bilge, where the nature of the separate duties necessitates operation at opposite ends of the pump range. It will readily be seen from Figure 21 that for both duties the

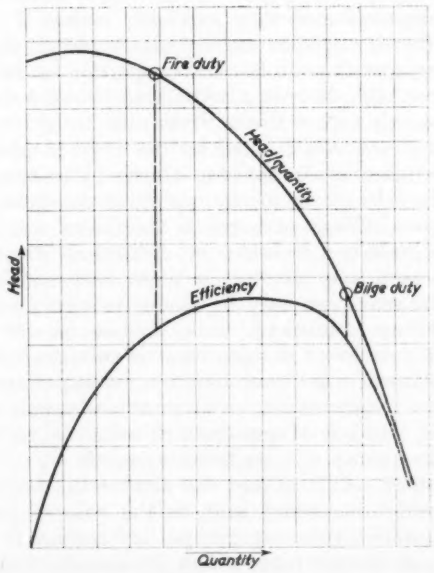


Figure 21. Relative operating points on pump characteristic for typical fire and bilge duties.

pump is running under inefficient and unfavorable conditions. When fire pressure requirements were fairly low and d-c variable speed motors were used, this set of conditions could usually be accommodated by employing a liberal speed range, but constantly rising fire pressures and the use of a-c supply have resulted in conditions where separate pumps for each duty present an attractive alternative. With this arrangement a small high speed non-self-priming type pump, giving a performance as indicated in Figure 22, could be used for the fire duty and a larger, slower speed, self-priming pump with air pump for the bilge duty, resulting in a considerable saving in the running costs of the pumps, not only in bhp consumed but also in maintenance.

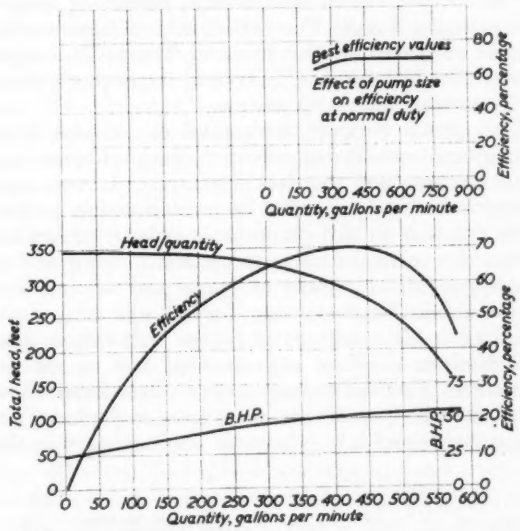


Figure 22. Performance of 5-in. high speed mid-mounted centrifugal fire pump.
Speed: 3,500 rpm

Oil Separation from Bilge Water

Since legislation has come into force with regard to the discharge, in navigable waters, of water contaminated with oil, it has entailed the fitting of oily water separators to clean the bilge water of oil before pumping overboard.

When the separators are only capable of dealing with between say 30 and 50 tons per hour at a maximum pressure of 15 psi, the pump manufacturer is frequently requested to state the speed and pressure at which say a 200 tons per hr bilge or ballast pump should operate to supply the separator. If the shape of a centrifugal pump head/quantity characteristic is considered, as shown for instance in Figure 12, the practical difficulties in attempting to obtain the greatly reduced flow in this way are easily appreciated. One method of achieving the required conditions would be to install an orifice meter and pressure gauge in the discharge line to the separator and throttle the pump to give the desired output.

The use of a large pump under throttled conditions seems inherently wrong, however, for such a duty, since conditions inside the pump promote thorough churning and mixing of the medium being pumped and a smaller pump of correct capacity to match the separator, or a suitably designed water operated ejector, should prove more satisfactory.

CARGO PUMPING

Cargo Oil Pumps

Although rotary vane type pumps are still employed for tank stripping duties, despite their size and weight, and steam reciprocating units also continue to be used for such duties and for cargo pumping in refined product carriers, where only moderate pumping rates are involved, the centrifugal pump with its inherent advantages of saving in space and weight, ease of maintenance and continuous shock-free delivery, is now well established as the most suitable type of cargo pump where large pumping rates are involved.

Special Requirements

Cargo pumping, entailing the handling of water, petrol or oils, of viscosity up to 4,000-sec. Redwood No. I, places many special requirements on the pump design and fittings.

Since the pump has to be capable of handling low boiling point liquids, impeller inlet areas must be as generous as possible; the impeller inlet and the pump itself must be situated as low as possible relative to the cargo tank bottom; and suitable vent connections should be supplied connecting the pump to the stripping unit, in order to prevent vapor collecting at the impeller eye, and also to permit priming of the main cargo pump if required. Absolute oil tightness at the pump glands is of course particularly desirable for this type of pump.

Restriction of flow to the pump suction by strengthening frames, etc., near the bottom of a cargo tank, results in air/vapor entrainment which, if severe, causes the pump to lock or lose suction. From safety considerations, the pump must not be permitted to run without a throughflow for any length of time, since rapid overheating of the liquid in the casing would take place, but, in addition to an automatic safety device, such as the overspeed trip on turbine driven pumps, it is normal in first class pumps to cover for a limited period of dry running by providing liberal clearances in the pump with adjacent surfaces whitemetal lined.

Quantity adjustment is afforded by a screw-down sluice valve on the pump discharge. In addition a non-return valve is provided to prevent reverse flow through the pump when stopped or slowed down, and a rapid action relief valve with bypass back to the suction is fitted to protect shore lines against excessive pressure.

Typical Pump Designs

A typical horizontal turbine driven centrifugal pump designed to meet these requirements is shown in Figure 23. Drive between the prime mover and pump is transmitted through an intermediate shaft, passing through a special bulkhead fitting which contains a bearing and two stuffing boxes and provides an oil seal between the engine room and adjacent pump room to prevent gas leakage. The pump coupling is of the solid type to avoid sliding friction in the pump room, flexibility being provided by the driving unit coupling, which is of the internal gear pattern. More recent developments of this bulkhead fitting are aimed at effective sealing with improved tolerance of relative movement between the prime mover and cargo pump. One such arrangement utilizes a special swivelling bulkhead fitting, containing a bearing and with a grease and/or oil seal between the fittings and an intermediate "floating" shaft. A later design uses a flexible metal bellows between the bulkhead and the stationary bearing bracket of the pump. The seal on the rotating shaft is then formed by the pump bearing itself, lubricated and made gas tight by a grease supply or supplemented by a seal. With this latter design the shaft bearing, and seal if fitted, are always in alignment and relative motion is taken up by the bellows and the intermediate "floating" shaft, which is in this case wholly on the engine room side of the bulkhead.

The pump is a two-stage design, the first-stage impeller being of the double-entry type, and is fitted in this instance with ball and roller bearings, although the journal loads may equally well be taken by whitemetal lined bearings, these being particularly suitable with the type of bulkhead seal mentioned latterly.

The stuffing boxes are fitted either with header turns retaining a petrol resistant grease or plastic packing medium, or are fitted with mechanical seals. The split casing design follows the now normally accepted practice of providing rapid access to the rotating element without disturbing pipe connections. The two-stage design of pump in general gives a somewhat better effiiciency, even on water, and the fall in performance when pumping high viscosity oils is much less than with the single-stage unit, particularly in the small sizes. Suction performance is also better, due in part to the reduced speed at which the two-stage unit operates.

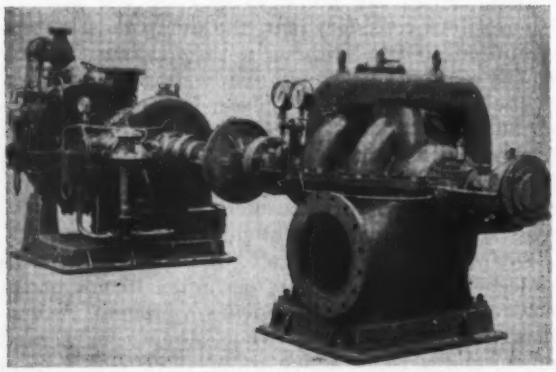


Figure 23. Two-stage turbine driven centrifugal cargo oil pump.

The demand for still larger crude oil tankers attendant on the post-war policy of building refineries near to the areas of consumption rather than the source of oil has resulted in the need for higher pumping rates. It is of interest to note in this connection that as capacity increases, for a given discharge pressure, the advantages in efficiency and suction performance of the two stage pump become less marked, and an increasingly good case can be made for the use of single-stage pumps of simple and compact design. The variation in efficiency with size is indicated in the inset to Figure 24, which shows the performance of typical large single-stage and two-stage cargo oil pumps.

The choice between horizontal or vertical units is to a large extent dependent on the particular ship arrangement, but the fact that from suction considerations the pump must be located as low as possible relative to the cargo tank bottom somewhat favors the vertical design, to avoid a driving unit in the bilges. Misalignment of pump and driving unit is inevitable between ship loaded and ship light conditions. With horizontal pumps this necessitates intermediate shafting with stuffing box or seal as described. Vertical pumps on the other hand allow good turbine location, in an alcove extended from the engine room into otherwise unused space in the

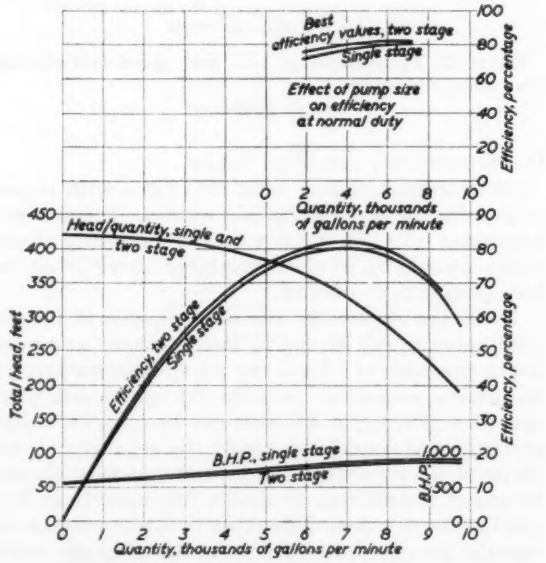


Figure 24. Performance of 18-in./16-in. single-stage and two-stage centrifugal cargo oil pumps.
Speed: 1,250 rpm. Sea water.

pump room, and permit the use of a simple oil bath seal at the bulkhead. They do however require the use of a "floating" shaft in the pump room. Assuming a split casing design in both cases, opening up for inspection is equally facile, but removal of the rotating element requires additional floor space to be available for vertical units. Unsplit casings, which can be dismantled vertically after disconnecting the intermediate shaft, are also practicable for the vertical arrangement.

Driving Unit

The most convenient method of cargo oil pump drive so far established is by a geared steam turbine. Although the highest practicable efficiency is desired for these turbines, particularly in Diesel tankers using waste heat boilers, they are only operated for short periods and have to be robustly constructed, so that turbines with a single-pressure stage having a two-row wheel are usually adopted. The cargo pumping is usually controlled from deck, and the turbines have remote reading electrical tachometers and remote speed control, which may either be by a remote steam valve or by remote operation of the speed governor. Dangers and limitations of speed control are noted later.

Although they are controlled from the deck, cargo oil pumps are not regarded as deck machinery, but they do have rougher operating conditions than those to which turbine driven machines are normally subjected; and this is taken into account in the design of their protective equipment. As the oil level falls below about 3 feet in the tanks, the speed of the pump should be reduced progressively. This may not always be done and the pump will cavitate, allowing the turbine to overspeed and trip out. Excessive use of the emergency trip gear is undesirable, and a flyweight governor may be arranged to stop the machine on overspeed by releasing oil pressure from the low oil pressure trip normally included in these machines. Sometimes the same flyweight governor is used to control speed in normal operation as well as to stop the machine on overspeed. The centrifugal overspeed governor is set for a higher speed and should operate only in an emergency.

Whatever type of speed governor is fitted it should be arranged to keep control of the speed from full pump output down to zero output with closed discharge valve. But the steam throttle valve should not be able to close tight and should pass enough steam to overspeed and trip the turbine if the pump cavitates or loses suction. Alternatively, the governor may be arranged to keep control of the turbine even with the pump empty if a device is fitted to trip the turbine when the temperature rise across the pump exceeds a predetermined value, since, as mentioned before, it is dangerous to allow a cargo oil pump to continue running empty or with insufficient oil flow to keep the temperature down.

In view of the flat head/quantity characteristic of a centrifugal pump, and since the head varies as the square of the speed, there is a danger in using speed variation to reduce the cargo pump capacity when flow to the suction strum fails to keep pace with the pump. If one pump is low in speed compared with the others discharging to the common shore line, this pump may be unable to hold its non-return valve open against the line pressure, and it would operate, therefore, under valve shut conditions. The method of adjusting capacity in this case should be to throttle the pump discharge valve at constant speed. The remarks regarding the inefficiencies of so doing, noted under "Condenser Circulation," are not so critical, due to the limited period of running under these conditions and the fact that oil is being handled.

Tank stripping arrangements now available include separate low capacity steam reciprocating or rotary vane type pumps with associated pipelines; an auxiliary air exhauster driven by, and used in conjunction with, the main cargo pump thereby affording self-priming; or a separate gas extraction system. In this latter arrangement the suctions of the main cargo pumps are connected to the exhausting system *via* a ball float, or liquid repelling device, to prevent the entrance of liquid.

GENERAL TOPICS

Use of a-c Electric Supply

In discussing the various types of pumps, the question of the move towards the use of alternating current as compared with direct current has been touched on several times.

From the pumping point of view the advantages of reduced unit maintenance are usually weighed against the difficulties of obtaining speed variation. In general however the need for variable speed centrifugal pump drives is much less than might be expected—in land applications it is seldom provided except for large boiler feed pumps. In most services if the pump size is well chosen it works, in a stable and satisfactory manner, under conditions indicated by the point of intersection of the pump head/quantity curve and the system resistance/quantity curve. If a variation is necessary, then instead of altering the pump performance by speed variation the system resistance may be increased by throttling or reduced by bypassing, with a corresponding variation in pump output. As mentioned under "Condenser Circulation" however, care must be exercised to avoid inefficient operation and it is recommended that such variation should be limited to between the approximate values of 70 per cent and 115 per cent of design capacity. If this is not sufficient, a motor to run at two alternative fixed speeds can be provided without undue complication.

A further point is that a-c motors should be run at as nearly full load as possible to ensure a good power factor for the ship's alternators and on this

account undue margins in motor power are to be avoided.

Accurate Estimation of Operating Conditions

This draws attention to a design question which applies to units with a-c or d-c motors, or steam drive, but which has been emphasized by the restrictions imposed by alternating current, *viz.* the importance of correct assessment of the pumping capacity required from the pump and the corresponding system resistance, so that the smallest and most economical unit may be selected. Too often in the past has the facility of speed variation concealed undue overestimation of requirements. This has resulted in the use of a pump considerably larger and more costly than necessary, run, when installed, at a reduced speed. Since pump head varies as the square of speed and quantity directly with speed, reduction in speed of an over-large pump results in most cases in inefficient running, with consequent wear and tear on pump internals.

It is to be hoped therefore that the discipline imposed by the single-speed a-c motor drive will result in indirect and possibly unexpected reductions in the cost of pumps as well as motors and in the amount of upkeep they require.

First Cost, Running Cost and Upkeep

In conclusion, a few thoughts on cost may prove of interest. The first cost of a pump depends essentially on the weight and cost of materials used and the time expended in its manufacture. Since pump capacity varies directly with speed, and output pressure as the square of the speed, the size and weight can be greatly reduced by utilizing higher running speeds. A limit to speed increase is however set by the following factors:

a) Pump efficiency falls off above a certain speed, depending on the pressure required, thus increasing the running cost;

b) The smaller size of unit results in hydraulic wear and tear being concentrated on a smaller surface of metal with more severe results;

c) There is an increased rate of mechanical wear consequent upon the higher speeds.

Reduced cost of replacements and of the labor costs of maintenance may compensate in some measure for the decrease in useful life resulting from these factors.

As regards driving motors, cost appears to fall rapidly with speed till a certain speed is reached and then it levels off. This may however be tied up, at least in part, with quantity production and demand, in which case wider use of high speeds should eventually show a further drop in cost.

Setting aside the conflicting requirements of using higher speeds to reduce first cost and keeping speeds moderate to reduce running and upkeep costs, the centrifugal pump designer is faced with the basic question of optimum blade length/width ratio for the impeller—too long and narrow blades cause high fluid friction losses, while too short and wide blades fail to control the flow of water resulting in turbulence losses.

Although it cannot always be achieved, the ideal pump would therefore be designed to give the best hydraulic proportions for impeller and diffusion passages, with the speed of rotation selected to suit.

ACKNOWLEDGEMENT

The authors wish to express their thanks to the Directors of G. and J. Weir Ltd. and Drysdale and Co. Ltd. for permission to publish this paper and to their colleagues for assistance in the preparation of material. Acknowledgement is also made to the Admiralty for permission to publish information on boiler feed pumps supplied to H.M. Ships.

GAS TURBINE FOR AMPHIBIOUS VEHICLE

Conversion of a military amphibious landing vehicle to gas turbine power is now underway at Jered Industries, Inc., Detroit. Designated LVTPX-10, the turbine-powered craft is a conversion of the Marine Corps LVTP-5 personnel and cargo carrier. Jered is developing the craft for the Navy's Bureau of Ships. The new transmission system developed by Jered weighs under 3,200 lb. compared to more than 6,500 lb. in the replaced equipment. Space occupied by the turbine engine itself is only 9 cubic feet against 65 cubic feet for the reciprocating powerplant. Reduced physical size of the propulsion equipment combined with the transmission permitted moving the engine compartment bulkhead aft 5 ft. which enlarged the craft's cargo volume by 210 cubic feet or 33 1/3 per cent. LVTPX-10 will carry 46 fully equipped troops while the LVTY-5 now transports 34.

—Marine Journal, July 1960

IRVING GRANET, WILLIAM GUMAN & WILLIAM MCILROY

STUDIES OF A PLASMA PINCH SPACE ENGINE

THE AUTHORS

Irving Granet received his B.M.E. from The Cooper Union; his M.M.E. from Polytechnic Institute of Brooklyn; has taken Pre-Doctoral Studies at Polytechnic Institute of Brooklyn; and is a graduate of the Oak Ridge School of Reactor Technology.

He has worked in Republic's Plasma Propulsion Laboratory on nuclear propulsion systems, space radiators, thermodynamic power cycle considerations for generating electric power, and system design and operation for space propulsion. He was formerly Director of Staff Engineering, Nuclear Energy Department, of Foster Wheeler Corporation where he directed engineering design and analysis for complete nuclear plants. Mr. Granet has taught thermodynamics and heat transfer at the Polytechnic Institute of Brooklyn, and at present is Adjunct Assistant Professor of Engineering and Physics at Long Island University.

He has published over 40 articles in the fields of thermodynamics, applied mechanics, heat transfer and nuclear energy. He is a member of the American Society of Mechanical Engineers, National Society of Professional Engineers, Pi Tau Sigma and Sigma Xi. He is a licensed Professional Engineer in the State of New York. Mr. Granet is listed in the 1960 edition of American Men of Science and is a reviewer for the American Chemical Society's technical publications.

William J. Guman received degrees of B. Aero. E., M. Aero. E., from and has completed courses for Ph.D. Aero. E. at Rensselaer Polytechnic Institute. Since coming to Republic in 1959, Mr. Guman has been conducting theoretical and experimental studies on non-steady interactions and flow processes in plasma engine configurations. Mr. Guman was Assistant Professor at Rensselaer Polytechnic Institute lecturing on fluid mechanics, aerodynamics, performance and stability, and conducting laboratory courses in experimental fluid dynamics and wind tunnel research. He also investigated flow induction and was head of Rensselaer's supersonic wind tunnel laboratory. Mr. Guman performed a theoretical analysis in experimental aerodynamics at Avco, and conducted analyses of experimental flight test data at Grumman.

Mr. Guman has authored papers published in the Journal of the Institute of The Aeronautical Sciences, Journal of Applied Physics, Journal of the American Rocket Society and the Physics of Fluids. Mr. Guman is listed in the 1960 edition of American Men of Science and is a member of the Institute of the Aeronautical Sciences, Tau Beta Pi, Gamma Alpha Rho and Sigma Xi.

William McIlroy received degrees of B.Sc., M.Sc., and Ph.D., all in mechanical Engineering from Queens University, Belfast and B.Sc. in Mathematics from London University. He has taken courses on Control and Guidance, Royal Military College of Science; Courses on Propulsion at the College of Aeronautics, Cranfield, England; and Courses on Aerodynamic Heating, Missile Aerodynamics and Plasma Dynamics at Massachusetts Institute of Technology.

Since coming to Republic in 1955, Dr. McElroy has participated in systems analyses and in studies of plasma physics, magnetohydrodynamics, internal gas dynamics, and aerodynamic heating and combustion. As a Post-Doctorate Fellow at John Hopkins University, Dr. McElroy investigated turbulent boundary layers and assisted in the theoretical design of blading for jet engines. At Short Bros. and Harland, Ltd., he supervised the mathematical, aerodynamical, structural and performance studies, worked on control and guidance problems, and other phases of aircraft design.

Dr. McElroy is a member of the Institute of Aeronautical Science, Royal Aeronautical Society, and has written papers on magnetohydrodynamics and Republic reports on aerodynamic heating and on the plasma pinch engine.

INTRODUCTION

THE REQUIREMENTS of an engine that will operate under the unusual and severe environmental conditions that exist in space are unique. It is not sufficient to speak of such items as capital costs, efficiency, etc. The emphasis lies with reliability, light weight, high exhaust velocities to give maximum thrust per pound of propellant, mission requirements, etc. In many instances these considerations require novel technologies to be developed before engineering solutions can be reached. It is also apparent that the classical distinctions in engineering (i.e., Mechanical, Naval, Civil, Electrical, etc.) do not apply since this new field encompasses all of these disciplines as well as other sciences. It is, therefore, necessary that all branches of the engineering sciences become familiar with this new discipline. Since 1957, Republic Aviation Corporation's Plasma Propulsion Laboratory has been actively engaged in the field of plasma science with the object of understanding the basic processes and to develop a pulsed plasma engine suitable for space applications.

The use of the electromagnetic pinch effect for propulsion has been described in several references [1, 2, 3]. In this engine capacitors are discharged across two nozzle-shaped electrodes wherein a radial pinch is converted to axial motion of the ionized gas between the electrodes (see Figure 1). A "magnetic piston", caused by the intersection of a thin cylindrical current sheet (discharge) with its own induced magnetic field, sweeps the gas between the electrodes out of the nozzle. A shock wave is formed which overtakes the stationary gas. Velocities of 70,000 meters per second have been obtained and it is anticipated that velocities up to 100,000 meters per second can be achieved if desired.

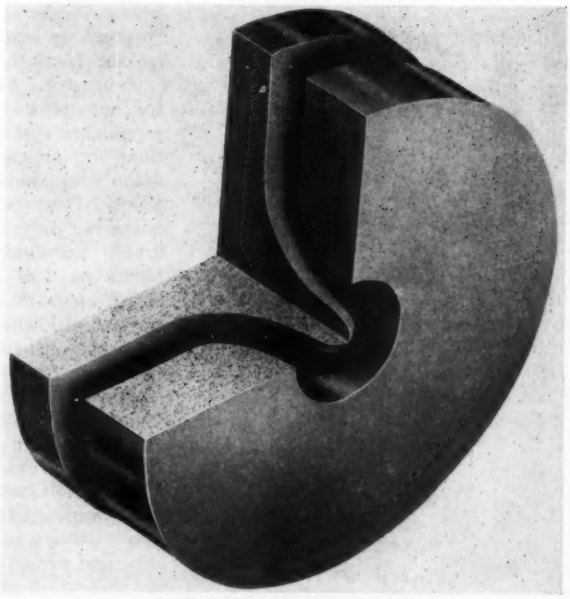
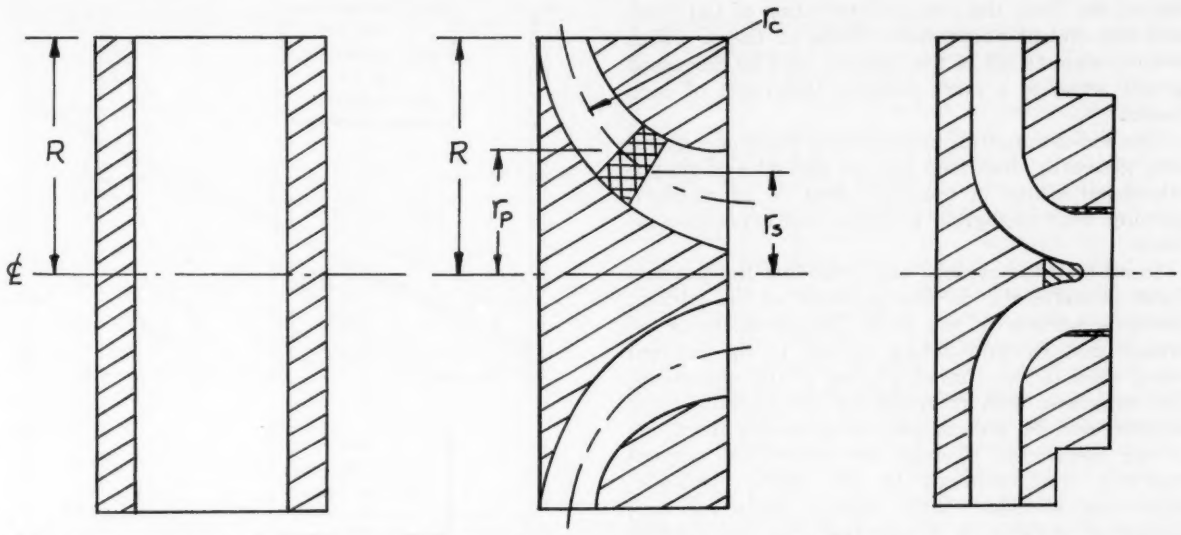


Figure 1. Nozzle Electrodes

Three types of electrodes have been used for experimentation and they are illustrated in Figure 2. The cylindrically symmetrical electrodes (Figure 2a) are similar to the linear discharge electrodes which have been the subject of much experimentation for controlled thermonuclear fusion. The "one



Cylindrically Symmetric Electrodes One Dimensional Nozzle Electrodes Radially Dominant Nozzle Electrodes

Figure 2. Three Types of Pinch Experiments

dimensional" nozzle electrodes (Figure 2b) are designed with a constant cross-sectional flow area throughout the annular path. The width of the annular path is considered small enough relative to the average radius of curvature of the flow path that a one dimensional, time dependent, flow analysis can be applied. The nozzle electrodes of Figure 2c were designed to permit the maximum length of radial travel before turning the driven gas in an axial direction. An analysis of the electrode geometry to yield maximum work on the plasma by the electric circuit is currently being carried out.

The results obtained with each of these electrodes indicate the following:

1. A cylindrically symmetrical pinch can be easily obtained with many shapes of electrodes and different gases and the phenomenon can be repeated many times with the same quantitative results.

2. The formation of the initial skin current (i.e., the initiation process), herein called the "magnetic piston", is fully determined by the initial circuit and gas conditions. The location of the initial current is always at the outer radius of the electrodes and the current path has been found to be axisymmetric.

3. The familiar Lorentz force created by the interaction of the skin current and its self-induced magnetic field (no externally applied magnetic field is required) is acting uniformly on a surface normal to the desired flow lines between the electrodes. This latter statement is true at least prior to any sharp curvature of the electrodes.

4. Essentially all of the initial bulk motion produced in the radial pinch appears in a directed, readily usable thrust producing sense. This leads to a highly efficient method of energy utilization for propulsion. A pilot engine has already been operated uninterrupted in a vacuum chamber for 118 hours.

Based upon the foregoing and other pertinent considerations, it has been concluded that the radial pinch effect is a practical and simple principle for the realization of space propulsion systems.

A brief discussion and comparison of four analytical models of the radial pinch and their application to a specific geometry and set of system parameters are also discussed below.

GAS DYNAMICS

Currently several analytical models are used to analyze the pinch process. While some of these rely on non-continuum fluid concepts, most analyses approach the problem from a continuum fluid point of view. In particular, four models are examined below as they apply to a thrust producing radial electrode geometry. The analytical models that will be briefly discussed are:

1. The "snow plow" model [4]
2. The "quasi-steady" or "hydrodynamic" model [1]
3. The "slug" model [5]
4. The "gasdynamic" model [6]

The conservation equations required for a coupled electrodynamic-gasdynamic analysis are the continuity equation, the momentum equation, the energy equation and an electrical circuit equation. Simplifications are generally introduced to reduce the complexity of the overall problem. The additional simplifying assumptions are usually applied to one or more of the following: the electrode geometry, the electrical and magnetic properties of the fluid, the gasdynamic and thermodynamic proper-

ties of the fluid, the initial distribution of the fluid, and the circuit parameters. Some of these, which are common to all of the models, will be discussed briefly prior to a more detailed treatment of each model.

The axi-symmetric, non-ablating electrode geometry generally discussed has for the sake of simplicity been either of constant area or of constant spacing with negligible resistive and capacitive effects.

In all of these models, one finds that the Lorentz force provides the driving pressure at the current carrying portion of the fluid. This pressure is assumed uniform and acting normal to the current sheet even in the curved portion of the electrodes. The magnetic field required for the Lorentz force is generated by the current which passes from one of the electrodes, through the cylindrical current carrying fluid element to the other electrode, neglecting boundary layer effects. Again for simplicity of analysis, it is assumed that the current carrying fluid element has zero electrical resistance (i.e., infinite conductivity) and also negligible energy is required to establish and maintain this conducting sheet. The assumption of infinite conductivity in the presence of the magnetic field implies that no ionized particles can cross the conducting sheet. Finite conductivity would permit electrically neutral fluid to cross the interface because of the hydrodynamic pressure difference that is present. This can be seen from the physics of the interface. The general boundary condition at the interface is that the sum of the magnetic pressure plus hydrodynamic pressure is constant across it. For an infinitely conducting fluid only hydrodynamic pressure can exist in front of the sheet since the magnetic field can not penetrate the sheet. Behind the sheet both a hydrodynamic and a magnetic pressure can occur. It is this hydrodynamic pressure difference that can cause some leakage of electrically neutral fluid across the sheet. In general it is found that the hydrodynamic pressure behind the interface is negligible compared to the hydrodynamic pressure ahead. It is for these reasons then that all of the models assume that at the interface the magnetic pressure behind the sheet can be equated to the hydrodynamic pressure ahead of it. From this one can qualitatively reason that the shock Mach number of a magnetically driven strong shock should be approximately equal to the square root of the ratio of the magnetic pressure to the free stream hydrodynamic pressure. Figure 3, based upon strong shock considerations, shows the relation of shock Mach number to pressure. Since magnetic pressure depends on current, it is postulated that the shock or interface velocity or their respective Mach numbers are related to the instantaneous current. This has been established from the snow plow model and was found to be a simple functional relationship for the first quarter

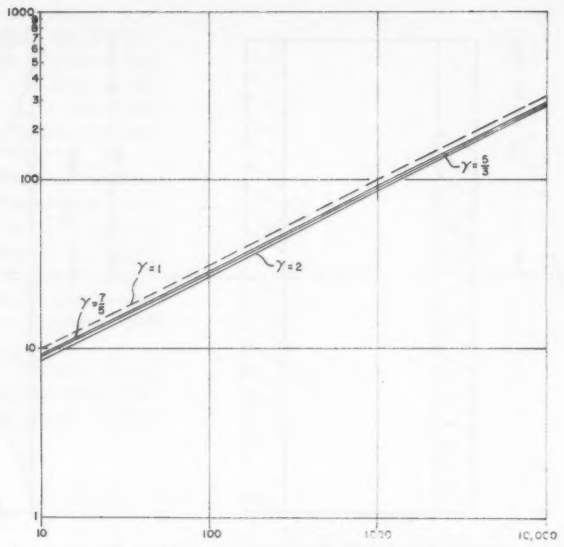


Figure 3. Shock Mach Number as a Function of Pressure Ratio

cycle of the current for all of the models. [7].

As in many other complex gasdynamical problems, the fluid is considered inviscid, ideal, adiabatic and to have constant specific heats. Compressibility is taken into account in the quasi-steady model and in the gasdynamic model. However, in the quasi-steady model, one of the implications of the quasi-static assumption is that pressure signals can pass instantly through the entire body of fluid. This assumption is justified by noting that most of the available experimental data indicate that the distance between the current sheet and the shock is very small and hence traversed by pressure signals in negligible time. The quasi-steady model is useful only during the first quarter cycle of the current.

Another condition usually imposed is that all gasdynamic parameters within the electrode assembly are uniform before initiating a pinch. This of course is true in thermonuclear work or in any laboratory setup where the electrode assembly is located in a stationary medium. In a propulsion system one can not expect the fluid to be uniformly distributed. This is because the pinch process must be repeated in order to produce thrust, and in order to do so, new fluid must be present in the nozzle assembly before the pinch can occur. Fluid introduced into the pinch chamber will tend to distribute itself in the chamber and in the case of space propulsion, leak out of the nozzle assembly. The distribution of fluid and the leakage flow provides the fluid with an initial velocity and a non-uniform distribution of thermodynamic properties. Thus, in general, a uni-

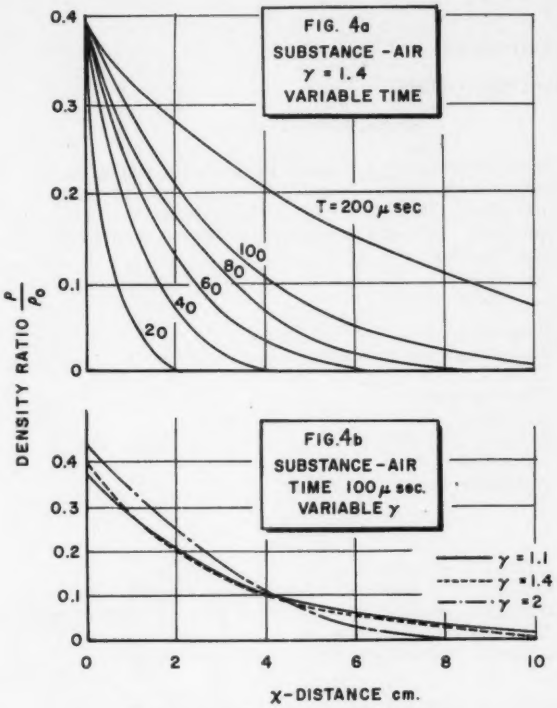


Figure 4. Density Distributions

form distribution of fluid properties and zero initial velocity is not truly a correct initial condition for the pinch process as applied to a propulsion system. Recently the snow-plow analysis has been extended to cover the general case of non-uniform initial conditions (both mass distribution and velocity) [8]. Figure 4 shows the density distribution for typical cases presented in [8].

Of the circuit elements, the external capacitance, resistance and inductance are assumed constant and invariant with respect to time. All of these elements are in a series circuit and displacement currents are neglected even when the circuit is allowed to ring [9] on the gas.

Briefly, the four models discussed distinguish themselves in the manner by which the actual nonsteady gasdynamic action occurring between an advancing shock front and an electrically conducting fluid sheet is approximated. In the *"snow plow model"*, all of the fluid overtaken and energized by the actual shock front is assumed to be located in a uniform manner in a very thin layer at the electrically conducting fluid sheet. The entire body of fluid swept out and located between the shock and the conducting fluid sheet is assumed to be moving at the same speed as the fluid sheet and is driven by the force due to the magnetic pressure existing at that instant. This conducting fluid sheet is commonly referred to as a "magnetic piston" because of the similarity of the behavior of a slab of a perfectly conducting fluid sheet in the presence of a magnetic field with a solid piston. The *"quasi-steady"* or *"hydrodynamic model"* assumes that at any instant of time one has an advancing shock front overtaking stationary fluid. The fluid overtaken is assumed to be at uniform conditions and located between the shock and the magnetic piston and moving at the piston velocity. The shock velocity and piston velocity are assumed to be related by the Rankine-Hugoniot strong shock relation at any instant of time. The magnetic pressure existing at any instant is taken to be identically equal to the hydrodynamic pressure behind the shock at the same instant. The *"slug model"* assumes that all of the fluid mass that is to be energized is a fixed quantity for all time and is situated at the piston face from the instant at which acceleration commences. Also, this body of fluid is treated as a quantity of matter unaffected by the lack of fluid ahead of it. The *"gasdynamic model"* makes an effort to include the nonsteady gasdynamic motion between the shock and piston and beyond, by applying finite difference techniques to the governing conservation equations. The shock is replaced by a thin layer across which the gasdynamic parameters vary rapidly but in a continuous manner. A continuous nonsteady flow field is achieved throughout by suitably introducing an artificial dissipative term which transforms the hyperbolic differential equations into nonlinear parabolic form. Table 1 summarizes the assumptions which are the basis of each of the models.

ELECTRODYNAMIC CONSIDERATIONS

The electric circuit considered consists of a capacitance, (C_e), a resistance (R_e), an inductance (L_e) and a plasma pinch chamber. Due to the movement of the "magnetic" piston, the electrode geometry and the piston position introduce a time-varying inductance into the circuit (L_p). In the present paper the capacitance of the pinch chamber and the resistance of the plasma (which is a function of degree of ionization and temperature of plasma) will be neglected. The appropriate electrical circuit equation has been derived very elegantly by Neuringer [9] using energy concepts, and from his analysis the distribution of energy in the circuit can be clearly seen. The governing circuit equation reduces to

$$\frac{d^2}{dt^2}\left\{L_{TOTAL}i\right\}+R_e\frac{di}{dt}+\frac{i}{C_e}=0 \quad \ldots\ldots\ldots\ldots (1)$$

or may be written,

$$L_e\frac{d^2i}{dt^2}+R_e\frac{di}{dt}+\frac{i}{C_e}=-\frac{d^2}{dt^2}\left\{L_pi\right\} \quad \ldots\ldots\ldots\ldots (2)$$

The left hand side represents the contribution of the external circuit, while the term on the right represents the inductive effect of the contracting plasma. Normally it is assumed that the initial posi-

TABLE 1-A

SUMMARY OF ASSUMPTIONS

(Snow Plow Model and Quasi-Steady Model)

SNOW PLOW MODEL	QUASI-STEADY MODEL
MASS	
Mass continuously picked up during acceleration. Mass picked up assumed accumulated in a thin layer at the advancing current sheet. Mass to be picked up distributed in any manner if considered in equations. (Usually considered uniformly distributed and at rest.)	Mass continuously overtaken by advancing shock distributed uniformly in space between current sheet and shock. Mass can initially be at rest or moving uniformly. (Usually considered uniformly distributed and at rest.)
FLUID	
Continuum	Continuum
Perfect gas (or modified)	Perfect gas (or modified)
Inviscid	Inviscid
*Infinitely compressible	*Compressible
Adiabatic, infinite thermal conductivity	Adiabatic, infinite thermal conductivity
Picked up mass, infinite electrical conductivity	Infinite electrical conductivity at a thin current sheet only
Negligible energy to ionize	Negligible energy to ionize
Magnetic pressure » local static pressure at the current sheet and » initial chamber pressure	
PINCH AND GEOMETRY	
Implosive or explosive	Implosive or explosive
Lorentz force uniform and normal at current sheet	Lorentz force uniform and normal at current sheet
Negligible resistive and capacitive effect of electrodes	Negligible resistive and capacitive effect of electrodes
Non-ablating electrodes	Non-ablating electrodes
Constant area or constant spacing electrodes	Constant area or constant spacing electrodes.
ELECTRICAL	
External capacitance, resistance, inductance constant	Constant external capacitance, resistance. Total inductance constant (decoupled case)
Plasma inductance variable	Circuit elements in a series circuit
Circuit elements in a series circuit	Displacement currents always neglected
Displacement currents always neglected	
GOVERNING EQUATIONS	
Non-linear	Linear (electrodynamic and gasdynamic equations decoupled for simplified numerical analysis)

* Rankine-Hugoniot strong shock relations assumed to apply at every instant.

tions of the return conductor and the piston are coincident at the outer electrode radius. If this is not so, there will be an initial plasma inductance which can be included in the external inductance term.

The inductance of the plasma can be expressed in the form

$$L_p(t)=\frac{\mu}{4\pi^2}\int_o^x \frac{A(\xi)\,d\xi}{r^2} \qquad (3)$$

where A = cross sectional area between electrodes which contains the magnetic field

x, ξ = distance moved by "magnetic" piston along the flow path

r = mean distance of piston from the axis of symmetry

For cylindrical geometry, L_p reduces to

$$\frac{\mu l_o}{2\pi}\log_e(R_o/r)$$

where l_o equals electrode space at radius R_o while for "constant area" electrodes as have been used experimentally at RAC,

$$L_p=\frac{\mu l_o R_o}{2\pi}\int_o^x \frac{d\xi}{r^2} \qquad (4)$$

In a propulsion system, it is desirable to predict the partition of condenser energy in the circuit. [9] shows that the power expended by the condenser across the pinch chamber goes into (1) increasing magnetic energy due to the time rate of change of current at the instantaneous value of the plasma geometry (L_p) which is equivalent to $L_p i\, di/dt$, and (2), the energy required to keep the current constant with a changing plasma geometry $i^2\, dL_p/dt$. One half of this second term goes into magnetic energy, while the other half $\frac{1}{2}i^2\, dL_p/dt$ is easily proved to be equal to the rate at which mechanical work is done on the plasma.

Consequently, of the energy expended by the condenser at a given instant of time, an amount

$$\int_o^t L_{TOTAL}\, i\frac{di}{dt}dt+\int_o^t \tfrac{1}{2}\, i^2\frac{dL_p}{dt}dt = \tfrac{1}{2}\, L_{TOTAL}\, i^2 \qquad (5)$$

TABLE 1-B

SUMMARY OF ASSUMPTIONS

(Slug Model and Gasdynamic Model)

	SLUG MODEL	GASDYNAMIC MODEL
MASS	Fixed quantity always located at advancing current sheet No mass ahead of or behind current sheet	Mass continuously overtaken by advancing shock distributed between shock and current sheet, taking into account nonsteady flow processes. Initial mass can be distributed in any manner.
FLUID	Not considered a fluid Continuum Inviscid process Incompressible substance Adiabatic, infinite thermal conductivity Infinite electrical conductivity Negligible energy to ionize	Perfect gas (or modified) Continuum Inviscid Compressible Adiabatic Infinite electrical conductivity at a thin current sheet only Negligible energy to ionize Shock replaced by an artificial diffusion process
PINCH AND GEOMETRY	Implosive or explosive Lorentz force uniform and normal at current sheet Negligible resistive and capacitive effects of electrodes Non-ablating electrodes Constant area or constant spacing electrodes	Implosive or explosive Lorentz force uniform and normal at current sheet Negligible resistive and capacitive effect of electrodes Non-ablating electrodes Any area variation
ELECTRICAL	External capacitance, resistance, inductance constant Circuit elements in a series circuit Displacement currents always neglected Inductance variable due to motion of slug	External capacitance, resistance, inductance constant Circuit elements in a series circuit Displacement currents always neglected Plasma inductance and resistance variable
GOVERNING EQUATIONS	Non-linear	Non-linear, solved by method of finite differences

is in the magnetic field and recoverable, an amount

$$\tfrac{1}{2}\int_0^t i^2 \frac{dL_p}{dt}\,dt$$

has been transformed into kinetic plus thermal energy of the accelerated plasma, and an amount

$$\int_0^t i^2 R_e\,dt$$

has been wasted in joulean heat. It appears desirable, therefore, to "ring out" the electric circuit until all the condenser energy is expended to provide the maximum utilization of energy, or alternatively to disconnect the circuit by means of a switch as the current goes through its zero values, i.e., at end of half cycles. In this way, the full amount of field energy can be recovered by the condensers. [7]

It is immediately obvious that the amount of work done on the plasma is greater, the greater its inductance relative to the external inductance. The internal inductance of the plasma is controlled by the geometry of the pinch chamber, so it appears that most advantage can be achieved by maintaining the external inductance at the lowest possible values. The external resistance also should be kept as small as possible, so as to avoid excessive joulean dissipation of the current wave form. It can be demonstrated that for optimum conversion both L_e *and* $\frac{R_e}{2}\sqrt{\frac{C}{L_e}}$ should be made as small as possible. In [10] the linear pinch in cylindrical electrodes is analyzed using the quasi-steady method, and its results indicate the dependence on geometry and electrical characteristics. The "pinch time", defined as the time taken for the piston driven shock to reach the center line, was made to correspond to the quarter cycle time when the external resistance was zero. It was found that with increasing $\frac{R_e}{2}\sqrt{\frac{C}{L_e}}$, the pinch time increased as a result of the much reduced current maximum. For relatively large values of the damping factor, the current remained almost constant after reaching its maximum value. The results also indicated that the magnetic work on the plasma (for given initial energy on the capacitor) initially increased quite rapidly and then more slowly as the ratio of maximum plasma inductance to the external circuit inductance was increased.

From the foregoing it appears that in general,

for optimum operation, a study of the most desirable electrode configuration for maximum magnetic work input is required. Such a configuration would entail maximizing the integral

$$\tfrac{1}{2}\int_0^t \frac{d}{dt}\left\{\frac{\mu}{4\pi^2}\int_0^{x(t)}\frac{A\,d\xi}{r^2}\right\}dt = \frac{\mu}{8\pi^2}\int_0^t i^2\,\frac{d}{dt}\int_0^x \frac{A\,d\xi}{r^2}\,dt$$

subject to the condition that the mass of gas is fixed

$$= \int_0 2\pi r\,\rho(\xi)\,dA$$

for a given external circuit configuration and capacitor energy. This must be done keeping in mind the gasdynamic requirements of small electrode spacing to radius of curvature ratio for one dimensional type flow, and no boundary layer separation. Such an analysis is currently in progress. Other results of analytical studies are further indicated in the next section.

ANALYTICAL RESULTS AND CONCLUSIONS

Experimental data from the Republic plasma pinch engine reveal that roughly 10 percent to 25 percent of the capacitor energy appears as kinetic energy of the plasma being discharged. Analytical studies have been carried out at Republic showing that the efficiency achieved experimentally is far from optimum. A few of the electrodynamical and gasdynamical techniques for increasing the efficiency will now be briefly presented.

It has already been pointed out earlier in this paper that of the energy available from the capacitor not all of it will be transformed into mechanical work. The distribution of available energy in the various forms that this energy can assume was examined for a wide range of parameters using the snow plow analysis programmed on an IBM 704 computer [7]. At any instant the energy out of the capacitor was equated to the kinetic energy of the plasma, circuit heating (i.e., joulean dissipation), the magnetic energy in the external circuit, and the magnetic energy residing in the plasma. The results of this analysis showed that the ratio of kinetic energy to the energy out of the capacitors at any instant is an increasing function of time which indicates the desirability of ringing the circuit on the plasma. Figure 5 shows the variation of kinetic energy, circuit heating and magnetic energy associated with the plasma for one of the many cases examined (the magnetic energy in the circuit has been deleted for sake of simplicity of presentation). For a given accelerator geometry and mass to be accelerated, the number of current cycles that would ring out on the plasma was found to depend on electrical circuit parameters. A most significant result was that the plasma momentum was found to be an increasing function of the number of quarter cycles with which the current would ring out on the moving plasma. Figure 6 shows the ratio

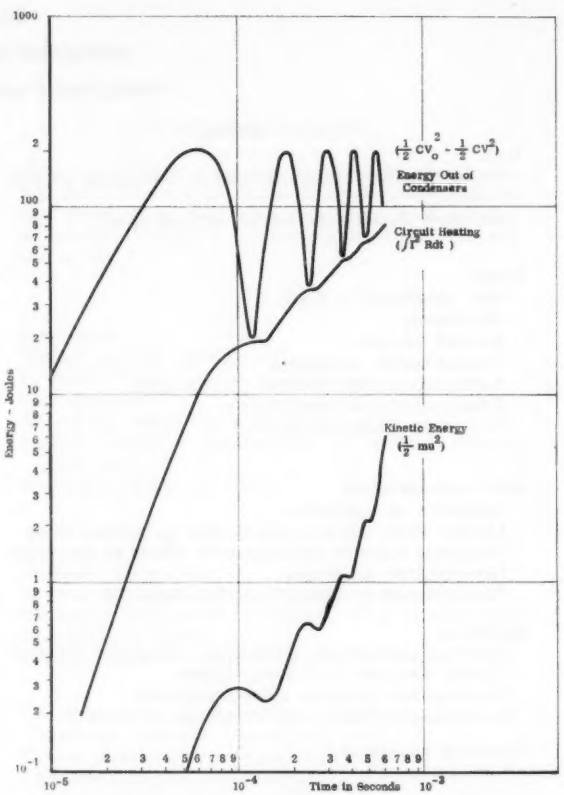


Figure 5. Energy time relations for selected items

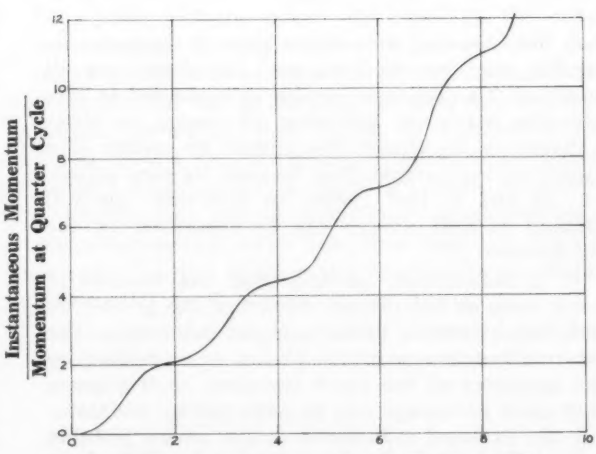


Figure 6. Momentum Increase due to Ringing on Plasma Current Quarter Cycles

of instantaneous momentum to the momentum at the quarter cycle as a function of the number of quarter cycles of current ringing for one of the many cases examined. Qualitatively, the other cases examined exhibited this same increasing momentum relationship. From a propulsion point of view this mode of operation is desirable because the momentum, i.e., thrust achievable, is increased. In Figure 7 the variation of efficiency of transfer, i.e.

$$= \frac{\text{kinetic energy of the plasma}}{\text{original energy stored in the capacitor}}$$

has been nondimensionalized in respect to its value at the current quarter cycle. The effect of ringing shows clearly an increase in the efficiency. It is significant to note that of the energies among which the original energy in the capacitor is distributed, the magnetic energy stored due to inductance vanishes when the current is zero. This is immediately apparent from an inspection of the circuit equation [9]. Hence the plasma should leave the accelerator when the current passes through zero, or when the current is very nearly zero such as is the case after a few cycles of damped ringing on the plasma. This technique precludes residual energy residing in the field [7]*. Discharging the plasma from the accelerator when the current passes through zero without switching off the current mechanically from the capacitor is not sufficient, for the plasma expanding from the accelerator can still form a conducting current loop with the electrical circuit. This has been observed experimentally at Republic. Since super fast acting electrical switches designed for this type of application

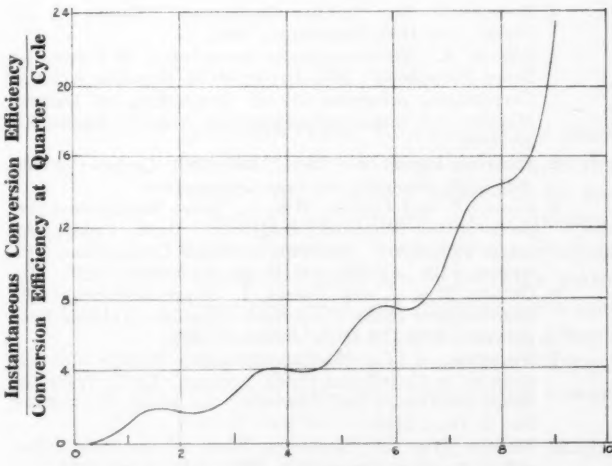


Figure 7. Energy Increase due to Ringing on Plasma Current Quarter Cycles

(service life and reliability) are not available, it is believed that the ringing technique will provide both a simple and highly efficient mode of operation for a pulsed type propulsion device. However, in order to ring out properly on the gas it is necessary to have a frequency high enough so that relaxation processes do not become significantly large with the consequence of a loss of ionization and possible loss of the current carrying skin. It is therefore in order briefly to consider the requirements for achieving a pinch since these must be dependent upon the electrical circuit parameters.

The first requirement for the pinch is therefore that an electrical discharge must occur. One may postulate that the sequence of events could start with a "Townsend Shower," proceeding to a glow discharge and thence to an arc discharge. It is during this latter stage that the so-called current sheet is formed. Once established, it is necessary to have continued increase in the time rate of change of current so that the magnetic pressure on the outer surface of the sheet exceeds the gas pressure in the sheet and a radially directed motion will start. The time (and distance) required for the formation of a strong shock varies inversely as the acceleration of the affected gas. Thus it is necessary that the rise in magnetic pressure should occur in a time that is short compared to the propagation time of a weak pressure signal. In order that the action initiated shall continue, it is necessary to achieve and sustain high currents in relatively short times.

If the magnitude of the peak current is large but the rate of rise of the current (after the arc discharge state) is small compared to the time for a weak pressure signal to propagate, the shock will not form. Under these conditions the gas in the duct will be heated at essentially constant pressure and the maximum velocity that occurs will correspond to Mach 1.

Based upon these and other considerations, the writers' conclusions regarding the initiation of the pinch may be summarized as follows:

1. A pinch can not exist in a continuum if the current carrying sheet is not established. To establish the current carrying sheet (skin) it is necessary to meet certain frequency and conductivity requirements. This "pre-pinch" condition is currently under investigation.
2. It is necessary to have a rate of current increase above a certain minimum (based upon geometry, gas, etc.) if one is to achieve a pinch (i.e., $\frac{di}{dt} > a$).
3. To sustain the pinch the peak current must also exceed a minimum (not necessarily the same minimum as for $\frac{di}{dt}$), i.e., $i > b$.
4. The two criteria, i and $\frac{di}{dt}$ must be jointly satisfied.

It is appropriate to discuss briefly the problem of charging capacitors from a power source. An extensive study of this problem has recently been com-

* It has come to the attention of the writers that in a recent paper Kantrowitz has also reached this conclusion.

pleted at Republic [11, 12, 13] and the following conclusions were reached:

1. The efficiency of energy transfer to a condenser by DC charging through R with $L = 0$ is shown to be limited to 50 percent, *even if R is a function of time*. The 50 percent is the "conventional" conclusion that one finds in the literature.
2. Capacitor charging efficiencies greater than 50 percent can be achieved in practice by either shaping the voltage or introducing inductance into the charging circuit.
3. Using voltage shaping, it is shown that a "ramp" input voltage to the capacitor results in the maximum efficiency which approaches 100 percent.
4. Introducing inductance into the charging circuit also permits high charging efficiencies without the necessity of shaping input wave form. This mode of charging suggests an operating cycle in which the discharge cycle frequency is made equal to the charging cycle frequency. In this operation, the capacitors reach their optimum charge at the same instant that the discharge cycle is ready to operate. The pinch would automatically be triggered (without the need for switches) by the breakdown characteristic of the gas in the pinch chamber. This type of operation has been called "resonant charging" and appears very promising.

The work mentioned above indicates many possible methods of condenser charging which will yield charging efficiencies approaching 100 percent.

The studies mentioned above also have shown the possibility of increasing the amount of available energy to the plasma. In an actual plasma accelerator, a considerable amount of the energy input to the plasma appears as non-thrust producing thermal energy. If a pulsed plasma accelerator operating in a vacuum is constructed so that the shock arrives at the front interface of the injected fluid inside the nozzle after the current has terminated, the subsequent flow of propellant will have the kinetic energy larger than the internal energy. In a pulsed plasma accelerator operating in a vacuum where gas is injected just prior to the generation of the shock, this injected gas, due to expansion, will be moving. The kinetic energy behind the shock thus exceeds the thermal energy. A shock colliding with gas expanding as a complete rarefaction wave examined one-dimensionally in an ideal fluid has the initial rarefaction wave transmitted as a complete rarefaction wave. In the interaction the shock strength changes with time. Hence there will be an entropy gradient following the shock. Approximating the flow field behind the shock by conditions across a centered complete rarefaction wave where the initial flow conditions are governed by conditions behind a strong shock, enables one readily to determine the ratio of kinetic to internal energy behind the shock at any instant. Table 2 shows the results of this computation. [14]

TABLE 2

Ratio of Specific Heats	K.E./I.E.
1.0	1.00
7/5 (Diatomic Gas)	2.67
5/3 (Monatomic Gas)	3.34
2.0	4.00

It will be noted that the kinetic energy exceeds the internal energy significantly.

In the literature the statement has been made that behind the magnetically driven shock of a pulsed type plasma accelerator, the internal energy will equal the kinetic energy. As a matter of interest, the derivation for this result assumes that the shock moves into a gas at rest, the pressure and enthalpy ahead of the gas are negligible compared to their respective values behind the shock, and that one is dealing with a magnetically driven shock. The analysis when applied to a shock overtaking a uniformly moving fluid will show that the kinetic energy will always exceed the thermal energy.

In summary, it should be noted that capacitor charging efficiencies of the order of 90 percent can be achieved and that conversion efficiencies of 80 percent are anticipated for the pulsed pinch plasma engine. From the foregoing, it appears reasonable to expect an optimum overall system efficiency (excluding the efficiency of power generation) for a pulsed pinch engine operating in space of the order of 70 percent.

REFERENCES

1. Kunen, A. E., "The Electromagnetic Pinch Effect Applied to a Space Propulsion System", PPL Report #108, Republic Aviation Corporation, August, 1958. Presented at A.A.S. West Coast meeting, Stanford University, August, 1958.
2. Kunen, A. E., and McIlroy, W., "The Electromagnetic Pinch Effect for Space Propulsion", PPL Report #116, Republic Aviation Corporation, August, 1959. Presented at A.R.S. Gas Dynamics Symposium, Northwestern University, August, 1959.
3. Kunen, A. E., Granet, I., and Guman, Wm. J., "The Plasma Pinch Engine", presented at Second Symposium on Advanced Propulsion Concepts at Boston, Massachusetts on October 7-8, 1959, Republic Aviation Corporation, PPL Report #124, September, 1959.
4. Rosenbluth, M., "Infinite Conductivity Theory of the Pinch", LA-1850, September, 1954.
5. Schock, A., "Electromagnetic Acceleration of Plasma for Space Propulsion", PPL Report #118, Republic Aviation Corporation, presented at 4th Symposium on Ballistic Missiles and Space Technology, Los Angeles, August 24-27, 1959.
6. Progress Report #1, May, 1959. OSR Contract AF49-(638)-552, Republic Aviation Corporation.
7. Granet, I. and Guman, Wm. J., "Some Engineering Aspects of the Magnetohydrodynamic Pinch Process for Space Propulsion", Republic Aviation Corporation, PPL Report #120, AFOSR TN 60-86, November, 1959.
8. Guman, Wm. J. and Granet, I., "Pinch Dynamics with Non-Uniform Initial Conditions", Republic Aviation Corporation, PPL-TR-60-6, January, 1960.
9. Neuringer, J. L., "Electromechanical Energy Conversions in a Cylindrical Pinch Process", I.R.E. Trans. on Space Electronics and Telemetry, pp. 55-56, Vol. SET-5, No. 2, June, 1959.
10. McIlroy, Wm., "A Parametric Study of the Pinch", Republic Aviation Corporation, PPL #111, April, 1959.
11. Mostov, P. M. and Neuringer, J. L., "RC Charging Scheme to Optimize the Efficiency of Energy Transfer to a Condenser", Republic Aviation Corporation, PPL #104, May 9, 1959.
12. Mostov, P. M. and Neuringer, J. L., "LRC Charging Scheme to Optimize the Efficiency of Energy Transfer

to a Condenser", Republic Aviation Corporation, PPL #106, June 18, 1959.

13. Mostov, P. M. and Neuringer, J. L., "LRC Schemes to Optimize the Efficiency of Energy Transfer to a Condenser for Prescribed Variable R", Republic Aviation Corporation, PPL #113, September 7, 1959.
14. Guman, Wm. J., "On The Partition of Energy in a Pinch Type Plasma Accelerator", Republic Aviation Corporation, Plasma Propulsion Laboratory, PPL-TN-60-5, February 25, 1960.

APPENDIX A

TABLE A-1—*Equations of the Several Models*

CONTINUITY EQUATION
(constant spacing per unit width)

Snow plow model $m=\rho_o\pi(R^2-r^2)$ (1a)

Quasi-steady $\rho_1\pi(r_b^2-r_s^2)=\rho_o\pi(R_o^2-r_s^2)$ (1b)

Slug model $m_T=m_o=\text{constant}$ (1c)

Gasdynamic model $\frac{\partial}{\partial t}(r^a\rho)+\frac{\partial}{\partial r}(r^a\rho U)=O$ (1d)

($\alpha=O$ for 1 dim. flow)

MOMENTUM EQUATION

Snow plow model $-2\pi r p_m=\frac{d}{dt}\left(m\frac{dr}{dt}\right)$ (2a)

Quasi-steady model $p_m=\rho_o U_s^2-\rho_1(U_s-U_1)^2$ (2b)

Slug model $-2\pi r p_m=m_o\frac{d^2r}{dt^2}$ (2c)

Gasdynamic model $O=\frac{\partial}{\partial t}(\rho r^a U)+\frac{\partial}{\partial r}(r^a\rho U^2)+r^a\frac{\partial\rho}{\partial r}$ (2d)

ENERGY EQUATION

Snow plow model $\frac{dE_p}{dt}=\frac{I^2}{2}\frac{dL}{dt}=mU\frac{dU}{dt}+\frac{dm}{dt}U^2$ (3a)

Quasi-steady model $\frac{\gamma}{\gamma-1}\frac{p_o}{\rho_o}+\frac{U_s^2}{2}=\frac{\gamma}{\gamma-1}\frac{p_m}{\rho_1}+\frac{1}{2}(U_s-U_1)^2;\ p_m\gg p_o$ (3b)

Slug model $\frac{dE_p}{dt}=\frac{I^2}{2}\frac{dL}{dt}=\frac{d}{dt}\left(\frac{m_oU^2}{2}\right)$ (3c)

Gasdynamic model $O=\frac{\partial}{\partial t}(r^a E)+\frac{\partial}{\partial r}(r^aEU+r^apU)$ (3d)

where $E=\frac{p}{\gamma-1}+\frac{1}{2}\rho U^2$

CIRCUIT EQUATION

Snow plow model $-\frac{d}{dt}(L_pI)=L_o\frac{dI}{dt}+V-\frac{1}{C}\int_o^t Idt$ (4a)

Quasi-steady model $O=L_o\frac{dI}{dt}+V-\frac{1}{C}\int_o^t Idt$ (4b)

Slug model $-\frac{d}{dt}(L_pI)=L_o\frac{dI}{dt}+V-\frac{1}{C}\int_o^t Idt$ (4c)

Gasdynamic model

$-\frac{d}{dt}(L_pI)=L_o\frac{dI}{dt}+V-\frac{1}{C}\int_o^t Idt$

CUSP OF PLENTY—Physicists at Stevens Institute of Technology hope to confine plasma in a stable cusp, a shape resembling two chalices placed top-to-top, in a new approach to control of thermonuclear energy: the "Chalice" experiment now underway with the support of an AEC contract. Principal investigators Professor Samuel Koslov and Professor George Schmidt are to produce plasma by vaporizing and ionizing heavy hydrogen; heat and compress the ionized gas within two separate magnetic coils lying opposite each other; fire the two plasmas against each other on opening a magnetic "valve." If the cusp forms and holds, the first step will have been taken toward a practical thermonuclear fusion power source.

—Research/Development, August 1960

UP
UP
SHIP REPAIR SPEED GOES UP
AT NEWPORT NEWS

Today, over the 862-foot level floor of recently enlarged and modernized Dry Dock Two, roll new three-stage towers.

Starting with standard fork-lift trucks, these towers were designed and built in our own shops, like so many of Newport News advanced tools. These towers, as well as new rolling stages, easily put one to four men into working position anywhere alongside a ship's hull . . . and quickly move them from position to position.

Result, more men work more continuously on cleaning, painting, inspection and repair. Big overhead cranes, that once did this work-positioning job far less efficiently, are freed to handle heavy duty repairs. Up goes overall overhaul speed. And your ship is often ready to go back into profitable service days sooner.

Whatever your ship repair, overhaul, building or conversion requirements, Newport News has the team and facilities to save you time and money.

Newport News
SHIPBUILDING AND DRY DOCK CO.
NEWPORT NEWS, VIRGINIA

LIEUTENANT ROBERT J. BOSNAK, USCG

AN ADVANCED CONCEPT FOR COMMERCIALLY PROFITABLE LAND AND MARINE NUCLEAR POWER: THE HIGH TEMPERATURE GAS COOLED PEBBLE BED REACTOR

THE AUTHOR

is a graduate of the U. S. Coast Guard Academy Class of 1948. Assignments have included various Coast Guard Ships, a Loran transmitting station, and a tour as an instructor in the Science Department at the U.S. Coast Guard Academy. At the time of writing he was enrolled in the postgraduate course in Naval Architecture and Marine Engineering at Massachusetts Institute of Technology.

ECONOMICS OF THE SITUATION

When Congress authorized construction of the first nuclear powered merchant ship, there was little doubt that it was technically feasible, but whether or not nuclear propulsion for merchant ships would prove commercially feasible was a question about which much has been said, both pro and con. The answer to this question appears to be that the present types of water reactors now in use, and modifications thereto, may at best, barely approach commercial feasibility. There may be certain exceptions to this which the operation of the NS *Savannah* will help to clear up. These appear at present to be long range tankers, bulk carriers, and possibly liners. The commercial operator thus has no compelling counter-reason to use nuclear power such as the priceless strategic advantages afforded naval vessels.

If we are to have any nuclear merchant vessels, it thus seems they must be government subsidized. Such is the case with the *Savannah* and such will be the case with any of the nuclear tankers the Maritime Administration would like to build in conjunction with the Maritime Reactors Branch (MRB) of the AEC. The Maritime Administration is presently interested in a 60,000 ton 30,000 SHP surface tanker, and also a 20 knot 20,000 ton submarine tanker. Much design work has already been accomplished but Congress has not as yet authorized construction. General Electric has been working on the preliminary design phases of a boiling water reactor for the surface tanker.

Data [1] compiled by the MRB is presented in

tabular and graphical form. The data refers to studies conducted on a 20,000 SHP tanker presumed to be on a long run from the United States to the Middle-East via Cape of Good Hope and the Persian Gulf. Table I lists power plant weights only for the PWR vs. conventional plants in 1960 and 1967. Table II shows a cost breakdown based on estimated United States costs in 1961. Nowhere do these costs include necessary research and development monies. Table II assumes that construction

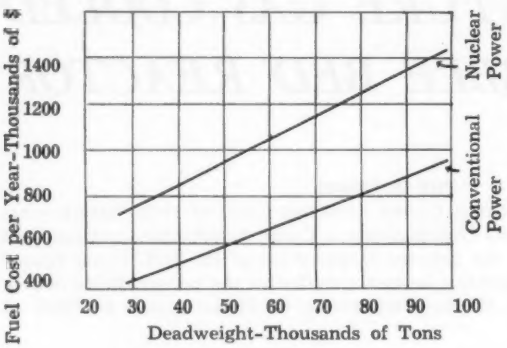


Figure 1

NOTE: Nuclear vs. conventional fuel costs on annual basis for tankers to Persian Gulf. AEC-MA group thinks two lines will actually converge, not diverge, with nuclear power being relatively less costly per unit in larger applications.

costs will probably be lower by 1961 than they were in the first ship (the *Savannah* cost 12 million). Figure 1 compares nuclear vs. conventional tankers on fuel costs alone. A 20,000 SHP conventional tanker costs about 35 cents per each 0.5 lb. fuel/SHP-HR (equivalent to 10^6 BTU). Best estimates put this figure at about 55 cents for a PWR tanker operating on a long distance run. Less favorable runs would raise the figure considerably. Figure 2 compares the PWR and competitive boiling water reactor (BWR) plants on a capital cost basis. For comparison, the cost of a conventional plant of 17,000 SHP would be about 5 million. The boiling

TABLE I [1]—*Tanker Power Plant Weight*

(in long tons for a 20,000 SHP Tanker)

	1960		1967	
	Fossile	Nuclear	Fossile	Nuclear
Conventional machinery, wet..	770	935	750	648
Oil Boiler	240	—	240	—
Reactor	—	500	—	400
Shielding	—	1420	—	1160
Nuclear Plant Structure	—	65	—	50
Total Plant 1010		2920	990	2258
Pounds/SHP	111	321	109	250
Diesel Oil	9	227	9	—
Fuel Oil 3830		60	3800	—
Combined Total 4849		3207	4799	2258

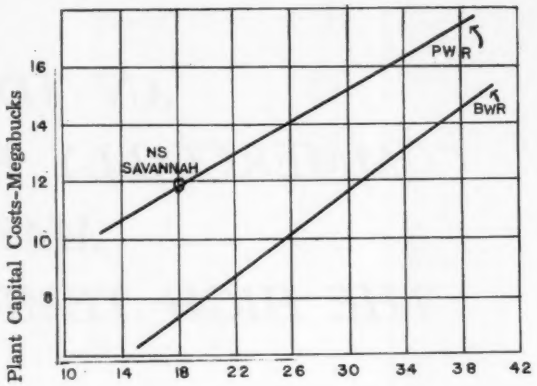


Figure 2

NOTE: PWR line based on B&W Study
BWR Line Based on AMF Study

COMPARISONS
Capital Cost-17,000 Conventional SHP-$5,000,000
PWR-$650/SHP
BWR-$450/SHP
Conventional-$300/SHP

TABLE II [1]—*Tanker Comparisons*

	38,000 DWT Tanker		85,000 DWT Tanker	
	Fossile	Nuclear	Fossile	Nuclear
Length, ft.	667	667	890	890
Speed, knot.....	17	17	17	17
SHP.....	17,000	17,000	32,000	32,000
Hull $.....	8,400,000	8,400,000	20,400,000	20,400,000
Power Plant cost $....3,000,000		9,000,000	5,000,000	15,000,000
Operating cost/yr $...2,045,200		2,726,700	3,887,500	5,005,800
Fuel cost/yr $.....	460,000	750,000	865,000	1,340,000
Amortization, $.....	684,000	1,044,000	1,522,000	3,120,000
Tons/yr at 5.3 trips.....	170,000	187,500	383,000	452,000
Cost/ton carried $.....	12.00	14.50	10.00	11.80

water plants then are considerably more economical than the PWR but still do not achieve real economic competition with conventional plants. Quite logically the next "generation" of maritime reactors may well be of the boiling water variety. By 1965 the third generation of reactors may be on the scene, and one of the most promising candidates for this role is the high temperature gas-cooled reactor (HTGR). Present studies indicate it has an excellent chance of affording commercially feasible nuclear operation. Early in 1958 General Dynamics received a five to seven year contract to develop a prototype gas-cooled reactor, closed-cycle gas turbine plant for merchant ship propulsion. Valuable data needed for further developmental work will

undoubtedly come from the operating tests of this prototype of the Maritime Gas-Cooled Reactor (MGCR).

No allowance was made for the special costs that a nuclear ship might encounter. It will fall to the *Savannah* to set necessary precedents and to ascertain all the pitfalls in the realm of port entry and clearance, health, and safety control, water and food supply, shore maintenance, waste disposal, insurance, marine law, etc. She will be a trail blazer in fields of special interest to the Coast Guard.

COST ANALYSIS—LAND REACTORS [2, 3, 4, 12]

It might now be interesting to compare land power plant costs to see just how competitive nuclear power is as far as the public utilities are concerned.

These figures are presented since there is no similar data for marine use. Such data will be forthcoming on completion of the *Savannah*. It is believed that relative cost differences between fossile fuel plants and the various reactor types will be in "the same ball park" as far as marine usage is concerned. At least until something better comes along, this is a starting point.

Table III, compares the capital outlay required for each plant. It also compares the average cost of producing electrical energy on a yearly basis. Fossile fuel costs are based on figures for an East Coast utility. Plants in other sections would have different costs.

Table IV gives a breakdown of the power production costs. Table V gives a detailed analysis of the production costs for a hypothetical PWR.

Important things to note in Tables III, IV, V are: (a) Capital outlay averages $200 more per Kw for water reactors than fossile fuel plants. This outlay has been reduced by $100 per Kw for the pebble bed reactor (PBR). (b) Only the PBR can produce electrical energy competitively. (c) The two items which bring costs way out of line on water reactors are (see table V) construction and fuel fabrication and reprocessing. These two items account for some 80 per cent of the total cost.

Any new design, such as PBR, must drastically slash construction and fuel costs to be competitive.

Most power companies and ship operators have been reluctant to go into nuclear power (water reactors) on their own because they are familiar with the uneconomical picture just presented. However, all agree that the United States could not just sit idly by and were more than willing, at first, to proceed with the government subsidizing the operation.

The AEC has proceeded very cautiously, thoroughly investigating all types of reactor configurations. Much has been learned in their development and credit for any future successes must be

TABLE III
Land Plants—Approximate 100 Mw [2, 3, 4, 12]

Name	Output (MW)	Capital Cost (10^6 $)	Ave. Capital Cost ($/Kw)	Ave. Production Cost (Mills/Kw hr)
Fossile Fuel	100	15	150	7.75
Shippingport (PWR)	60	68	1130	64.4
*Indian Pt. (PWR) (Con.Ed.,N.Y.)	275	90	328	13.6
*Yankee (Rowe Mass) (PWR)	134	50	370	11.3–14.1
*Dresden (Com. Ed., Ill.) (BWR)	180	—	≈350	10.5–13.1
*Pebble Bed (Sanderson +Porter)	125	32	252	7.46–8.07

(* Engineering estimate only; usually always too low)

TABLE IV—*Production Costs (Mills/KwHR) (Yearly Basis) Breakdown*

	Shipping-port	*Average PWR	Fossile Fuel	Pebble Bed (from design studies)
Fixed Charges	22.7	9.4	3.11	5.13
Fuel	38.4	9.2	4.25	1.48
Operation and Maintenance	3.3	1.0	0.39	1.0
Total costs	64.4	19.6	7.75	7.61

(* Average PWR represents an average pressurized water reactor building now. Costs are somewhat less than Shippingport and slightly higher than the others tabulated.)

TABLE V—*Breakdown of Costs in Table IV for Average PWR*

FIXED CHARGES		
Construction	8.2	
Start up and fuel investment	1.2	
Total Fixed Charges	.	9.4
Fuel U^{235} Burnup	2.2	
Fuel Fabrication and reprocessing	7.5	
Plutonium credit	(-)0.5	
Total Fuel Costs	.	9.2
Operation and maintenance	.	1.0
Total Cost		19.6

(Note: Percentage of total representing fuel fabrication, fuel reprocessing, construction is ≈80 percent)

laid to these early programs. However, to date none of the types built have achieved real commercial feasibility, and it appears that their refinements may not do too much better. Water cooled reactor types now being constructed, or their suggested modifications, have not yet been able to achieve steam at modern conditions of temperature and pressure. This further detracts from their desirability in the eyes of the private operator.

DESIGN CRITERIA FOR A NEW APPROACH

About five or six years ago quite a few commercial concerns in this country, in Canada, and in Western Europe became disenchanted with the current reactor development programs toward uneco-

nomical power. These companies included General Dynamics, Alco Products, Sanderson and Porter, C. D. Howe in Canada, and many private utilities in the United States. In Western Germany and Switzerland the companies included Brown-Boveri, Krupp, and Escher Wyss.

One glance at data similar to tables III, IV, V revealed the place to start their solution. Their new approach must (a) drastically reduce fuel fabrication and reprocessing costs, (b) eliminate the expensive construction materials for ordinary nuclear plants, (c) if possible produce a thermodynamic working fluid whose properties were such that it could fully utilize the modern conventional steam or gas turbines. A premium price must not be paid for special, less efficient low pressure turbine types. (d) In line with a and c, the design of the reactor must not be temperature limited by fuel elements, coolant, or structural materials. In so doing they also hoped to be rid of the five "curses"[13] of all water reactors. They are (1) Corrosion: Very pure hot water is much more corrosive than most people suspect. (2) Compromise: Structural strength in tubes and cladding, etc. must always be balanced against nuclear efficiency. (3) Complexity: The fittings on closely spaced tube ends become complicated high quality machined parts when all the design and service requirements have been met. (4) Cost: The cost per pound of components rises steeply as their quality and functional requirements become defined. Components initially visualized as plumbing fittings rapidly develop into accurately machined stainless steel parts. (5) Temperature limitation: These reactors have an inherent low temperature limitation which results in a low over-all thermodynamic efficiency.

Most of the forementioned companies came to the conclusion that gas cooling afforded a good way of achieving the desired end results. All of their new reactor concepts were generally classifiable under the heading of high temperature gas-cooled reactors. Design differences appeared in reactor configuration, fuel elements, material and shape, and exit and entry thermodynamic properties of the working fluid chosen.

The British have pioneered in gas cooling for many years. In this country General Dynamics is developing the MGCR for the Maritime Administration which was already mentioned to have a target date of 1963-65. The AEC is building a 25 MW(e) gas cooled reactor at Oak Ridge based on the joint design of ACF Industries and Kaiser Engineering, with completion scheduled for late 1962. This reactor has been named Experimental Gas Cooled Reactor (EGCR). A more advanced reactor than the Kaiser-ACF design will be built on the grid of the Philadelphia Electric Co. This reactor will have the title of High Temperature Gas-Cooled Reactor (HTGR) in the AEC's family of reactors. The core, to be designed by General Dynamics, will be helium cooled and produce 1450 psi 1000°F steam with an exit helium temperature of 1382°F. Philadelphia Electric Co. (PE) and 51 other utilities (High Temperature Reactor Development Associates Inc.) (HTRDA) will pay $24.5 million for the design and construction of the plant. The AEC will pay $14.5 million to General Dynamics in support of the reactor research and development work. Completion date is scheduled for October 1963. [11, 15, 16]

In this paper a description of the reactor type evolved by Sanderson and Porter and Alco in the U.S. will be undertaken. This particular one was chosen since Sanderson and Porter have published several papers on it. The reactors of the other companies are expected to differ in fuel element design but little literature is available.

THE PEBBLE BED REACTOR

Note: *all the following sections on the PBR have been adapted from* [5, 6].

For reasons which will become apparent this reactor type besides having the HTGR classification, is also called a pebble bed reactor (PBR). The design criteria already elaborated practically dictated that the reactor core, fuel and moderator be of a ceramic material operating at high temperatures with a gaseous coolant. Very early the design of the reactor system envisaged that the PBR would be an ideal reactor to operate with a closed cycle gas turbine. However, it could easily be used with a steam generator and conventional steam turbines. Large stationary power plant use will obviously be with steam for some time to come. The smaller units would lend themselves ideally to marine use with the gas turbine. For a small (approximately 10 MW) unit the gas turbine affords the known advantages of reliability, low maintenance, low operating cost, economy, maneuverability, minimum weight and space, and rapid starting. But to heat the gas above 1200°F so as to operate a gas turbine effectively requires that the reactor be so hot that occurrence of accidental hot spots might melt iron, nickel, zirconium, beryllium, and other metals now used in reactors. Most designs presented prior to the PBR would not permit practical operation of a gas turbine.

PBR DESCRIPTION

The reactor is all graphite construction with the core elements (small spheres) contained in vertical channels and the blanket elements contained in an annular ring around the core. The vertical channels would in effect be hoppers to contain the spherical fuel balls. These balls which can be used from ¼" to 2" diameter can be made with a standard pelletizing machine, to standard engineering tolerances.

Based on current prices, it would appear that the 20 KG critical mass in a 10 MW reactor could be filled for less than $10,000 fabrication cost, and conceivably it could be as little as $1,000. More detailed description of the fuel elements follows. Temperatures can get to 3600°F and higher without ill effects. The graphite fuel hoppers would be supported on a molybdenum grid with final support given by a steel bedplate which would support the entire structure including the reactor pressure vessel. All permanent graphite parts in the reactor would be treated with an impervious coating, such as a silicon carbide, which would prevent damage which might result from a steam leak into the primary system during the operation of a steam plant.

Control rods would be a boron molybdenum alloy. Preliminary calculations for the 125 MW central station reactor proposed by Sanderson and Porter indicate a core size 8.1′ high and 9.0′ in diameter, with reactor vessel 21′ by 13′8″. Figure 3 is cutaway view of the proposed Sanderson and Porter reactor.

Coolant Selection

Coolant gasses studied for possible use were air, helium, nitrogen, carbon dioxide, and crude neon. Air was eliminated because at the high temperatures involved, air would readily oxidize graphite and molybdenum. Nitrogen was likewise eliminated since it "oxidizes" molybdenum or tungsten at high temperatures. Above 800°F carbon dioxide reacts chemically with graphite so it too was discarded. Helium seems to be the ideal coolant. It is chemically inert and its neutron absorption cross section is practically zero. The heat transfer characteristics of helium are better than the other gasses. Looking ahead to future developments helium lends itself to use in the closed cycle gas turbine.

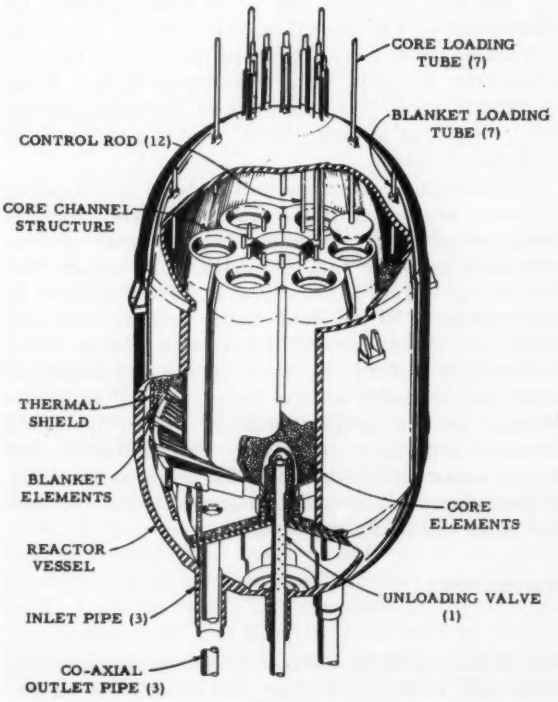


Figure 3

Sanderson and Porter's 125 eMW Pebble Bed Reactor 6

Crude neon is acceptable whenever helium is not available. It has a much higher absorption cross section than helium and hence reduces the neutron economy of the reactor.

Fuel

The fuel system of this reactor has been selected with the object of economy of production and processing. The PBR system was selected after study of a number of configurations of graphite-uranium types. The basic advantages this system affords are that the ceramic fuel elements are in compression, the system can be loaded and unloaded by relatively simple fluid handling techniques, and the spherical fuel element is amenable to a variety of compositions and mass production techniques.

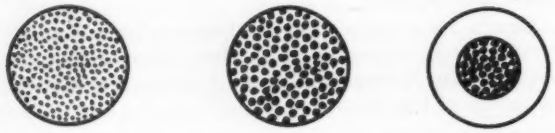
Studies made to date do not indicate any restriction with respect to the fuel cycle except that a partially enriched core is required to achieve a reasonable capital cost and fuel investment. PBR fuel systems investigated have been U235 burners and U233-thorium converters. A U233-thorium breeder and U235-plutonium converter are presently under study. The U233-thorium system has been questioned because of the present state of availability of these materials. However, this cycle has the desirable feature of permitting the operator to purchase his fuel supply, i.e. thorium, on the open market after establishing a full U233 loading. Availability of materials for the U233-plutonium is better and the system offers the possibility of the use of natural and/or depleted uranium as the feed material. Uranium, thorium carbides are chosen as the nuclear fuel because they can be heated to temperatures above 3600°F in contact with graphite and helium without appreciable reaction, vaporization, or the formation of gaseous products.

Since the structure and the coolant have extremely low parasitic capture cross sections, the system has good neutron economy. A high conversion ratio can be attained and breeding appears possible in certain sizes and configurations.

Fuel Manufacture

Three methods of manufacture are available for fabrication of the fuel elements for this reactor, namely impregnation of graphite spheres, admixture of fuel in graphite before molding the spheres, and lumping the fuel in a small sphere which is then jacketed with graphite during molding. These three methods of manufacture are being considered because each offers certain specific advantages. For example, the impregnated elements are amenable

to remote fabrication, the admixture elements will be less susceptible to radiation damage, and the lumped elements offer the greatest possibility of retaining fission products. A summary of the relative advantages of these fuel types is shown qualitatively in Figure 4.



Type	Impregnated	Admixture	Lumped
Retention of fission products....	3	2	1
Structural integrity under irradiation	3	2	1
% weight fissile material.....	3	2	1
Mechanical strength	1	2	1
Development of manufacturing technique	2	1	3
Economy of manufacture	1	2	3
Ease of remote fabrication.....	1	2	2

Figure 4. Relative Advantages of Fuel Element Manufacturing Methods. [5]
(where 1 indicates most advantageous)

Impregnation of graphite with uranium has been done on a laboratory scale by Argonne National Laboratory, North American Aviation, and the Los Alamos Scientific Laboratory. In general the process consists of impregnating preheated spheres (150°C) in a boiling uranyl nitrate solution, air drying, followed by baking at 275°C to drive off NO_2, and finally baking at about 800°C in a helium atmosphere. When graphite is impregnated with uranyl nitrate in this manner, the uranium is present as UO_2.

Fabrication of fuel elements by dispersion of UO_2 grains in a graphite matrix has been done on a laboratory scale by Battelle Memorial Institute, the National Carbon Company, and by the Great Lakes Carbon Company. In general the process is to blend UO_2 particles and graphite flour with a binder and mold to size under pressure. After molding, the ball is baked to core or in some cases to graphite, the binder. In the latter case, the uranium will be in the form of UC_2 rather than UO_2.

The third method of manufacture involves preshaping the fuel into a bulk form and adding the graphite around it. Thus the graphite becomes the jacket in the same manner as uranium slugs are canned in aluminum or zirconium. This method of manufacture has received only limited study to date.

Fuel Handing

Fuel handling involves removing all the core spheres and a fraction of the blanket spheres at the end of each core life. Fuel is loaded through multiple loading tubes at the top of the reactor and unloaded through a single discharge valve in the bottom. Flow is by gravity only.

A more advanced loading scheme involves the daily addition and removal of core material. This refueling schedule would allow an effective multiplication factor of only slightly greater than unity and would remove the need for large numbers of control rods which would otherwise be required to poison out the large initial excess reactivity present. Another advantage of this type of loading would be that it would peak axial power distribution near the top of the reactor which makes for good heat transfer since the cold coolant gas enters the core at the top of the reactor.

Fuel Reprocessing

Basically, reprocessing of this fuel element involves separating the graphite from the uranium and dissolving the latter in nitric acid which can then be fed directly to the conventional Thorex extraction process. The initial separating of uranium from graphite can be effected by incineration of the graphite or by crushing the fuel element and leaching out the soluble uranium oxide.

If the fuel elements are to be manufactured by impregnation, the uranyl nitrate effluent from the extraction columns can be used directly as the impregnating solution. It is contemplated that these operations would be carried out on the power station site in the case of land plants or at the terminal of a marine operator.

An interesting alternate to the above reprocessing scheme is suggested by the results of certain experiments reported by Atomics International on impregnated graphite fuel elements. They report that heating spent fuel of this type to 2000°C results in approximately 85 per cent of the total activity diffusing out of the element in from 4 to 6 hours. Thus it should be possible to reimpregnate and reuse the same fuel elements several times or until radiation damage to the graphite-matrix makes complete chemical separation necessary. Brown-Boveri and Krupp expect a lifetime of 10-15 years on the basis of their design studies. If this proves to be the case, fuel costs will really be slashed.

POSSIBLE PLANT CONFIGURATIONS

First Generation Steam [5, 6]

Such a reactor should be started by Brown-Boveri and Krupp in Western Germany this year. This is a 15 MW plant to be completed by 1962 and is to serve as a pilot plant for a later 100 MW station. Since Germany has no helium, crude neon containing 25 per cent helium is being used as a coolant necessitating extra fuel enrichment over the helium cooled reactor. Coolant gas will operate within a temperature range of 1112-1832°F. Outlet steam conditions from the steam generator should be about 1500 psi 1000°F.

The designers expect the finished plant to have an operating cost about the same as that of a conventional plant, construction costs will be only slightly higher, fuel costs will be lower since a fuel life of 10-15 years is claimed. This is made possible by the fact that the fuel may be reprocessed several times without complete chemical separation as previously described.

Both the Kaiser-ACF reactor (EGCR) and the Philadelphia Electric-HTRDA reactor (HTGR) already mentioned will, of course, be in this category, but the design for which most data are available is again Sanderson and Porter-Alco Product's 125 MW reactor [5, 6]. Its primary system consists of three steam generators in parallel. Helium is at a pressure of 965 psi and operates in the temperature range of 550 to 1250°F.

Each generator is essentially a tube and shell heat exchanger 8.5 feet in diameter and 35 feet high in which helium flows through the shell side and water through the tube side Hot helium enters through a 16 inch pipe at the bottom of the vessel and flows upward through a central 16 inch diameter duct to the region above the tube bundle. The helium flow then turns downward and flows across the tube bundles. The tube bundles are divided into three sections: a super-heating section, an evaporating section, and an economizer section.

Cold helium leaving the economizer section at the bottom of the unit turns and flows upward through the annulus formed by the pressure vessel wall and the thin stainless steel shroud which surrounds the tube bundles. Thus, the cold helium serves to keep the pressure vessel wall below 650°F and it is estimated that the maximum temperatures of the fuel elements will be 2170°F at the surface and 2440°F at the center.

This reactor has an inherent stability resulting from its negative temperature coefficient. The negative coefficient thus provides a basis for normal methods of power control which are effected by variations in the coolant flow. Three centrifugal blowers driven by synchronous motors are used for circulating the helium with flow control for gross power changes effected by either adjustable preswirl vanes or pressure level variations.

The 125 eMW PBR is designed to operate on the thorium-U235 fuel cycle. It has a conversion ratio of 0.863. The core area would contain 228,600 1.5″ diameter balls. The balls would be 90 per cent graphite and 10 per cent fuel-thorium and U233 in an 11-1 weight ratio. This corresponds to an 8 per cent enrichment. The blanket would contain 296,250 1.5″ balls of half graphite, half thorium oxide. The initial loading would have U235 or U233. From then on the plant would run on U233 made in the reactor and separated in an on-site fuel treatment plant. 90.2 Kg of U233 would be required in the core. The core would also contain 99.22 Kg of Th 232. There would be 11,780 Kg of Th 232 in the fuel producing blanket.

Cost estimates have already been presented and they should be reviewed, with some of the reasons for reductions now being in mind.

As experience develops with these plants, any desired steam pressure and temperature will be possible within the limits of the steam generator. The reactor imposes no limitations.

First Generation: Gas Turbine [14]

Size of the plant will probably be about 5-10 MW. Assuming a cost of approximately $300-$400 per Kw, capital costs would be under $4 million. No cost figures have yet been published for a plant of this type.

It is considered desirable to include a heat exchanger in the primary circuit of this plant. The unclad fuel elements will allow volatile fission products to diffuse through the graphite into the helium stream. The quantity of fission products which are released will depend on the method of manufacture of the fuel element and on the temperature of the core. The expected activity in the primary circuit is somewhere between that of a PWR and an aqueous homogeneous reactor. Whether such an activity level can be tolerated from the standpoint of maintenance or whether it must be reduced by the use of an impervious refractory coating on the fuel elements, or by the use of activated charcoal traps to remove all impurities from the helium is the major question confronting designers of this reactor. There are indications that this has been solved but is being closely guarded by the companies involved until issuance of patents.

For these reasons the first generation plant would employ a shell and tube heat exchanger.

Helium at approximately 225 psi 1350°F enters the tubes, leaving at 820°F. The turbine working fluid will be air. The air at 400 psi enters the turbine at 1250°F and leaves at about 750°F. The heat exchanger must be of quality construction since no leaks can be tolerated between the reactor-helium and turbine-air circuits. Turbine could be either closed or open cycle gas turbine but with eyes toward the future, a closed cycle turbine would be suggested.

Future Developments—Gas Turbine

The future possibilities of the gas turbine PBR appear much more dramatic than the steam turbine PBR. The costly heat exchanger may be removed reducing cost, weight, and space when the following conditions can be met: (a) a satisfactory level of primary radioactive contamination has been achieved; (b) turbine leakage has been reduced; (c) a helium gas turbine of proper size is available.

The Swiss have been working on the helium closed cycle gas turbine for a number of years. There has

been considerable concern expressed over the design of helium turbomachinery in the belief that it is a new field requiring appreciable research and development before such machinery can be constructed. This does not appear to be true. Acceptable turbomachinery can be built within the framework of our present knowledge. However, it is believed that the machinery can be improved somewhat by further research in the field of unorthodox blading, where Mach number limitation is not a consideration. [9]

Helium turbo-machinery built under present air design would probably have many more stages than would a plant specifically designed to take advantage of the fact that helium has no practical Mach number limitations in its blading design. Centrifugal stress limitations would be exceeded far before Mach 1 in helium was reached.

Expansion to large installations can come when large closed-cycle gas turbines are developed. A 60-MW turbine for helium has been designed. There appears to be no serious limitation to large sizes.

On the other hand, there are arguments for multiplying the 10-MW units for a single power installation. This type of reactor is uniquely favorable for use in non-industrialized areas; and it would be much easier to transport 10-MW size machinery, pressure vessels, and special equipment overland to distant places than it would be for 50-100 MW sizes. The multiple units permit a good deal of flexibility in operation and in shutdown for reloading or repairs, and they would minimize radioactivity hazards in case of accident. They appear to be the best bet for use in merchant vessels.

In long-range planning, the development of a molybdenum or tungsten turbine designed to operate with helium at 3,000 or 4,000°F should be undertaken. The thermodynamic efficiencies are greater at these temperatures and so it should be possible to use smaller, less efficient turbines and allow some low-temperature heat to be wasted. These metals cannot be used with combustion fuel because they will oxidize, but with helium there is a unique opportunity to pioneer in a new high-temperature range.

Advantages of PBR

We have seen that the Pebble Bed Reactor has a number of basic advantages which lead to low production costs when compared to present nuclear plant designs. Neither the core structure nor fuel and blanket elements require high precision manufacturing methods. The core structure, fuel and blanket elements and working fluid are all capable of operation at extremely high temperatures and therefore are not critical to hot spot and possible burn out. The use of helium, an inert gas, as a working fluid eliminates the need for costly corrosion resistant construction materials, or cladding. The use of fuel and blanket elements in a form amenable to handling by "fluid handling" techniques, reduces the costs associated with loading and unloading mechanisms. Power can be produced in conventional modern steam and gas turbine generating equipment. Reprocessing and fabrication of fuel units is simple and inexpensive. Neutron economy is excellent since absorption is low in coolant, moderator, and fuel units. Since the fuel units are not canned there is no canning metal to absorb neutrons. The high neutron economy allows reduction in fuel enrichment and cost, or gives better opportunity for conversion and breeding. There is no danger of explosion as in the water reactors, since there is no way to produce gasses by either overheating or chemical action. This may be particularly important with regard to insurance costs.

Disadvantages and Problems of PBR

The major disadvantage or problem, until eliminated, is the presence of radioactivity in the primary circuit. Another disadvantage is the fact that the automatic control in water reactors due to a density change in the coolant-moderator is not present in the PBR. A heavier responsibility will be placed on control mechanisms and variations in coolant flow. The isolation heat exchanger or the steam generator must be free of leaks to prevent contamination of the turbine. Leakage of helium at high temperatures must be thoroughly investigated.

Other areas requiring investigation in order to improve efficiency are fuel element stability under reactor operating conditions, heat transfer experiments, and the mechanics of ball manipulation. Major work is required in fission product technology to determine quantity and species of fission products released from the fuel elements, the nature of their deposition in the primary circuit, methods for their continuous removal, and methods of decontaminating and maintaining the primary circuit equipment.

CONCLUSIONS

We have seen that the PBR represents at least one solution to the problem of providing economical, efficient nuclear energy. Just how far it can go toward realizing the potential painted for it will probably remain unanswered until some of the pioneering plants now being started are completed and commence operations, which will be 1962 at the earliest. The best way of dealing with the activity in the primary circuit will not be resolved until experiments can be conducted in an operating plant. As soon as this major problem has been eliminated, the closed cycle gas turbine operating directly in the primary circuit will be practical. Until then PBR-gas turbines will require an isolating heat-exchanger.

PBR-steam plants will be the first to appear since they will be most important in land applications. PBR-steam plants will probably appear first in marine applications as well.

At this time it appears that the first gas cooled reactor-gas turbine plant will come as a result of the selection of General Dynamics by the AEC to develop the Maritime Gas Cooled Reactor (MGCR). The plant has to be a gas cooled reactor with closed cycle gas turbine and is to be completed by about 1965. This closed-cycle, gas cooled, nuclear marine plant represents the second stage of a joint AEC-MA program to achieve an economical merchant ship. The first stage is the NS *Savannah*.

In the final analysis, the attractiveness of any nuclear reactor system is reflected in its production and operating costs, since all the advantages and disadvantages of a particular system can be expressed in terms of these costs. This is the thing that most interests the prospective buyer. All that really can be said on this point in favor of the PBR has been brought out in the cost tables early in the paper. These figures merely represent the results of design studies. Final judgment will await the figures submitted by an operating plant. At this point all we can say is that the Pebble Bed Reactor holds the greatest promise and potential for achieving economical nuclear power.

BIBLIOGRAPHY

1. R. P. Godwin, *Nucleonics*, 15, No. 9, 114(1957).
2. D. P. Henon, *Nucleonics*, 15, No. 6, 73(1957).
3. *Nucleonics*, 16, No. 9, 75(1958).
4. J. A. Lane, *Nucleonics*, 16, No. 1 46(1958).
5. R. F. Benenati, *AIEE Transactions Paper 58-1110* (1958).
6. S. T. Robinson and R. F. Benenati, Sanderson and Porter, A high temperature gas cycle Pebble Bed for central station use (Information Meeting on Gas-Cooled Reactors, Oak Ridge National Laboratory, Oct. 21-22, 1958).
7. T. Sawyer, Gas Turbine Progress, *Mechanical Engineering*, Nov. 1958.
8. C. Keller and Spillmann, *Oil Engine and Gas Turbine*, United Kingdom; 21,317(1953); 21,355(1954).
9. S. T. Robinson, American Turbine Corp., *ASME Paper*, No. 57GTP13(1957).
10. C. Zeller, *ASME Transactions*, 1957. Closed Cycle Gas Turbine Power Plants.
11. *Nucleonics*, 16, No. 12, 17(1958).
12. Philip Sporn, *Nucleonics*, 15 No. 9, 104(1957).
13. J. A. Paget, *Modern Power and Engineering*, (Canada), 52, No. 9, 1958.
14. F. Daniels, *Nucleonics*, 14, No. 3, 34(1956).
15. *Nucleonics*, 17, No. 9, 26(1959).
16. W. S. Banks, *Nucleonics*, 17, No. 9, 76(1959).

SHIP REPLICAS

The news that a replica of the ***Bounty*** is being built in Nova Scotia makes it seem that there is a fairly steady demand for replica vessels. This demand is mainly in connection with public celebrations and the making of films. Sometimes it is thought good enough to get hold of some old craft and then to alter the above-water part so that it takes on the general appearance of the desired vessel. The new ***Bounty*** is, however, to be what might be called an authentic replica in that she is being built in more or less the same fashion as the original. In this respect, she will be like the ***Mayflower*** replica, which sailed across the Atlantic in 1957 and is now preserved in the U. S. The fact that the ***Mayflower*** made this passage took attention away from the American-built replicas of the Jamestown ships which were constructed at about the same time. The ***Susan Constant***, ***Godspeed***, and ***Discovery*** reached Jamestown in Virginia in 1607, and the replicas were built 350 years later. The replicas did not make any long passages, but they were all tried out under sail and performed quite satisfactorily. A point worth noting is the small size of the ***Discovery***. She was called a ***pinesse***, and was 30 feet long on the keel and 39 feet between perpendiculars. No one is quite sure how this tiny vessel kept in touch with the other two when they were at sea making the passage in 1607, the more so as it is believed that they had to weather a hurricane.

—Shipbuilding and Shipping Record, July 28, 1960

Revolutionary RCA Magnetic Video Tape Recorder to Speed Navigation Training of Submariners

Aboard the nuclear submarine Sea Dragon, the first undersea magnetic video tape recorder will record and store data on under-the-ice characteristics from externally installed TV cameras. Upon return to base the recorded information will be displayed for the benefit of undersea service trainees.

The RCA undersea recorder is a marvel of compact design (dimensions 20" x 20" x 100"). It nestles in a torpedo rack, and represents a 60% space reduction over existing video tape equipment.

Among the exclusive RCA developments are: the now famous "Tiros" satellite recorder; a radar system designed to take the first pictures of a nose cone re-entry vehicle; a unique tape cartridge completely adaptable to any size recorder. For literature describing new RCA defense and commercial products developments, write Defense Electronic Products, Radio Corporation of America, Camden, N. J.

Out of today's defense needs...tomorrow's electronic advances

RCA

The Most Trusted Name in Electronics

RADIO CORPORATION OF AMERICA

COMMANDER R. F. DESEL, USN, MR. L. E. CARLOW

THE USE OF WORK MEASUREMENT AND WORK STANDARDS FOR CONTROL OF PRODUCTIVE WORK IN SHIPYARDS

Commander Robert F. Desel, USN, a native of New York City, received a Bachelor of Science degree in Naval Architecture and Marine Engineering from the University of Michigan in 1943, and the degree of Naval Engineer from Massachusetts Institute of Technology in 1952. From June 1957 to June 1959, he was Production Analysis Superintendent of the Boston Naval Shipyard. He is presently serving as Design Superintendent at the same activity. He is a member of the Society of Naval Architects and Marine Engineers, The American Society of Naval Engineers, and Sigma Xi.

Lyman E. Carlow is a native of Washington County, Maine. He came to work in the Boston Naval Shipyard in 1929 as an apprentice in the Pipe and Copper Shop. After a period of time as a Planner and Estimator, he passed through the several shop supervisory levels and was appointed Master Mechanic in 1948. In 1955 he was appointed civilian head of the Production Analysis Division, recently re-organized as the Production Engineering Division.

PRODUCTIVE WORK, the world over, is valued by three criteria: quality, timeliness and cost. While these factors are necessarily interrelated, modern competitive practice emphasizes the last of the three by insisting on a minimum. This necessitates an attack on cost, independent of the other judgment factors. However, before this attack can be conducted on a rational basis, a base reference must be established. This reference must be expressed in units which will not be affected by factors which are beyond the direct control of management, e.g., wage fluctuations and raw material prices. The base is a productivity reference and, in this case, it is a performance standard, specified in terms of manhours of work to accomplish particular units of production.

The performance standard is a bench mark against which increases or decreases in productivity (per manhour of work) can be measured. It is as simple as this—to ask ourselves what should we expect to produce for a manhour of work. This concept of measurement is an integral part of our way of life. We find it applied daily in such atmospheres as the

grocery store with weights and measures marked on all commodities. If we reflect for a moment on the confusion that would reign if the contents of each quart and the weight of each pound were subject to the fancy of the individual grocer, it becomes apparent that the situation, wherein each of several hundred production supervisors decides what constitutes a day's work, leaves much to be desired. As in the case of the units of weights and measures, the units of productivity must be standardized. However, in the case of ship construction and repair activities the situation is complicated in that the units of production are not easily defined. The degree of difficulty, however, does not void the need for, or the value of performance standards as a basis for control of productive work.

Because of the need for cost control and a conviction of the potential value of cost control, the Naval Shipyards are embarked on an extensive program of developing performance standards in the most difficult of all industrial operations, i.e., job shop type of fabrication and repair. At the outset, the standards program had few backers. Most intimates were convinced that performance standards were unattainable for job shop type operations. However, after a few years of experience in this field, the writers are convinced that while the task has not been easy, it has been conclusively demonstrated at the Boston Naval Shipyard that job shop operations can be reduced to the "unit of production" definition. Therefore, these operations are susceptible to measurement in terms of performance standards. These standards vary from the classic mass production industrial engineering concept, only to the degree necessary for short run and non-repetitive type work.

At this point it should be stated that the greatest benefits which can be gained from performance standards are in the area of management.

The hardest look should be given to the provisions that are made by management to supply the productive worker with the where-with-all to produce, rather than the productive workers' pace or desire to produce. Men, material and plans must be scheduled and coordinated, methods must be improved, and positive leadership must be provided by supervision to gain the most effective utilization of manpower.

The goal of management is the control of productive work, and its costs, by means of standards developed through a dynamic program of work study and measurement. To be effective the program must produce standards that are not only practicable for continuous and economical daily use, but of sufficient flexibility to assure that improvements in scope and quality are incorporated as they are made.

IDENTIFY AND DEFINE MEASURABLE UNITS OF PRODUCTION

Before you can control you must first establish the means of measurement against which the control can be applied. The manhour is, in the truest sense, a unit of cost not subject to variations in wages and for this reason it is chosen as the yardstick for measurement. However, if the yardstick is to be meaningful as a measure of productivity, it must be related to specific, definable units of production. The first step in the measurement process is to identify and catalogue the units of production that are to be measured.

Ship repair work is largely non-repetitive in the sense that the specific operations to perform the same type of repair are seldom the same. Even that equipment which is most frequently repaired is seldom found in the same condition, or removed and re-installed under the same set of circumstances. After careful scrutiny of this situation, however, one prime fact emerges. In each trade there are basic elements or operations which, when put together in varying combinations and sequences, make up any job performed. For example, in the Pipe Shop there are certain things that are done to a piece of pipe. It can be cut, threaded, bent, welded, soldered, flanged. When the operations are further classified according to the size, thickness, material, and service of the pipe, they become measurable units of production which can be clearly identified and evaluated. When these units are put together with the sixty or seventy other operations performed in the Pipe Shop, they form the building blocks with which any job undertaken can be constructed and measured. In the Welding Shop the units are feet of weld classified by size, type, material and position. In the Boiler Shop the units become boiler tubes and refractory materials. In short, for each shop it is possible to identify basic units of production which can be evaluated and developed into tables of standard estimating data.

ESTABLISH TIME VALUES FOR PRODUCTION UNITS

The next step is to determine the measurement, or time value, for each unit. To gain this objective, several approaches may be used. For example, time values can be determined in terms of manhours by a satisfactory evaluation of cost records. This approach is limited by the fact that in many cases the jobs are not issued in such a way that the cost of the defined units can be clearly identified. In such cases the historical data must be supplemented by supervisory judgment and opinion, or by other factors such as machine cycle time, feed, speed, etc. In each case the manhour value set for each unit of production is certified by the senior shop supervisor as being a valid standard of work measurement. In the initial attempt, an effort should be made to exclude obvious instances of avoidable delay. The standards thus developed may be designated as "authoritarian" standards, and can be arranged systematically in standard data tables for each shop. Table I is an example of such an arrangement.

Tubes, Generating—1" Diameter						Prep'd.			Standard No. 41001 Rev. Original		D1		Sheet 1 of 1 Dated 30 Jan. 1958		
	Shipwork					Shopwork				Shipwork					
Quantity	Burn	Flush	Shrink Back Out	Clean Holes	Handle	Bend	Cut	Mill	Polish	Stick Hold On	Roll Off Mud Drum	Roll Off Steam Drum	Mill	Reroll	Bell	Handle Clean Up
1	.050	.042	.100	.037	.025	.400	.033	.025	.033	.150	.100	.083	.117	.117	.008	.040
100	5.0	4.2	10.0	3.7	2.5	40.0	3.33	2.5	3.3	15.0	10.0	8.3	11.7	11.7	0.8	4.0
200	10.0	8.3	20.0	7.3	5.0	80.0	6.7	5.0	6.7	30.0	20.0	16.7	23.3	23.3	1.7	8.0
300	15.0	12.5	30.0	11.0	7.5	120.	10.0	7.5	10.0	45.0	30.0	25.0	35.0	35.0	2.5	12.0
400	20.0	16.7	40.0	14.7	10.0	160.	13.3	10.0	13.3	60.0	40.0	33.3	46.7	46.7	3.3	16.0
500	25.0	20.9	50.0	18.4	12.5	200.	16.7	12.5	16.7	75.0	50.0	41.7	58.4	58.4	4.2	20.0
600	30.0	25.0	60.0	22.0	15.0	240.	20.0	15.0	20.0	90.0	60.0	50.0	70.0	70.0	5.0	24.0
700	35.0	29.2	70.0	25.7	17.5	250.	23.3	17.5	23.3	105.	70.0	58.3	81.7	81.7	5.8	28.0
800	40.0	33.4	80.0	29.4	20.0	320.	26.6	20.0	26.6	120.	80.	66.6	93.4	93.4	6.6	32.0
900	45.0	37.5	90.0	33.0	22.5	360.	30.0	22.5	30.0	135.	90.0	75.0	105.	105.	7.5	36.0
1000	50.0	41.7	100.	36.7	25.0	400.	33.3	25.0	33.3	150.	100.	83.3	116.	116.	8.3	40.0
1100	55.0	45.9	110.	40.4	27.5	440.	36.6	27.5	36.6	165.	110.	91.6	128.	128.	9.1	44.0
1200	60.0	50.0	120.	44.0	30.0	480.	40.0	30.0	40.0	186.	120.	100.	140.	140.	10.0	48.0
1300	65.0	54.2	130.	47.7	32.5	520.	43.3	32.5	43.3	195.	130.	108.	151.	151.	10.8	52.0

NOTE: a. For 50 tubes or less add 8 hrs. to shopwork, to shipwork removals, and to shipwork installation to cover set up and breakdown time because only a few tubes are involved.
b. Bending operation based on an average of three (3) bends per tube.

TABLE I. *An example of Standards of Standard Data Scope and Authoritarian Quality*

STANDARDIZE TERMINOLOGY FOR SCOPE AND QUALITY CONCEPTS

It is recognized that even though the work is technically non-repetitive, patterns of similarity exist in varying degrees, and accordingly standards can be developed having wide ranges in work scope. In such a circumstance, standardized terminology should be adopted. The following definitions are recommended:

A. *Job Order Standard*: A standard time for accomplishing all items of work instruction which are included in a total job order. A job order is authorization to accomplish an item of work (usually involving several shops) with a brief description of type and scope of work. A job order may define work as simple as repairing a cracked seam, or as complex as a major electronic installation.

B. *Job Standard*: A standard time for accomplishing all items of work instruction for any one shop which are included in a total job order. The terms Job Standard and Job Order Standard are synonymous for a one shop job order.

C. *Operation Standard*: A standard time for accomplishing one item of work instruction for a particular shop.

D. *Standard Data*: A standard time for accomplishing a basic production unit. (The Building Blocks) See Table I.

The standards that are developed may vary widely in quality according to the methods by which the time values are derived.

Quality will improve as the program progresses, and the methods for deriving time values become more precise. Therefore, it is essential that quality characteristics be defined. This is accomplished by the establishment of four levels of quality, as follows:

1. *Authoritarian*: A time value for a work item of any scope based on the consensus of management opinion, and for which avoidable delay time has been removed by authoritarian means. See Table I.

2. *Statistical*: A time value for a work item of any scope that has been verified by return costs. (Authoritarian Standards that have been verified by returns costs.)

3. *Modified Engineered*: A time value for a work item of any scope of statistical quality that has been refined by the removal of avoidable delay time and adjusted for pace. Avoidable delay time can be determined by use of accepted work sampling procedures. (See Table V)

4. *Engineered*: A time for a work item of any scope which is obtained by actual on-the-job observations of work being performed. This observation or time study is made after a careful definition of the scope of the work and a determination of the best way to perform the work. It includes pace rating the mechanic while performing the work.

COLLECT RETURN COST DATA

In the Boston Naval Shipyard initial efforts were concentrated on developing, in each shop, a maximum

number of performance standards of standard data scope and authoritarian quality.

It is a simple matter to collect return cost data under a two card timekeeping system. This system uses an electric accounting machine (EAM) time card clocked for attendance recording, and another which is marksensed for labor costing. All that is necessary to accumulate cost data on standards by scope and quality is to code the cost card in an appropriate manner when the labor charge is lodged. For this purpose the letters A through D represent the scope (from Job Order Standard to Standard Data, respectively) and the numbers 1 through 4 represent the quality (from Authoritarian to Full Engineered, respectively). By the addition of another simple code, standards may be grouped according to similar types of work.

In the process of collecting labor charges an EAM run is prepared, showing the following data for each shop:

1. Total manhours worked in each shop.
2. Total manhours worked under standard estimates, grouped by type of work, by scope, and by quality classifications.
3. Total standard estimated manhours for work accomplished under standard estimates, grouped by type of work, by scope, and by quality classifications.

DEVELOP STATISTICAL STANDARDS FROM RETURN COST DATA

Based on weekly EAM runs, each shop is evaluated with respect to the proportion of its work being carried out with standard estimates as a performance criteria. Further inspection of the data reveals the average expenditure related to the standard estimate to complete the same work (standard hours vs actual manhours worked).

As return costs of jobs in the category of standard data scope and authoritarian quality are compared with the standard hours, expenditure trends can be determined. Over a period of time these trends develop definite patterns by shop. For example, in one shop over a period of three months the actual hours worked are consistently 95 percent of the standard hours, and in another shop the expenditures are 127 percent of the standard hours. Table II represents an eight month accumulation of expenditure pattern for one shop. Once this relationship has been established for a shop, the amount by which its authoritarian standards must be adjusted in order to make them into statistical standards is known. For example, in a shop where the expenditures equal 95 percent of the estimate, a job whose time value was established at 100 manhours by the initial authoritarian standards now becomes 95 manhours statistically. In actual practice this step need not be taken. The data, however, can be used as part of the conversion from authoritarian standards directly to modified engineered standards. By definition, a modified engineered standard is a time value of statistical quality which has been refined by the removal of avoidable delay time—and adjusted for pace and personal allowance.

HISTORICAL EXPENDITURE PATTERN
BOILER SHOP

2 Week Period Ending	Hours Estimated On Standard (Authoritarian)	Actual Expenditures	% of Standard Actual Estimate
12/5/58	1100	1078	98
12/19/58	1194	1206	101
1/2/59	2685	2901	108
1/16/59	624	668	107
1/30/59	2882	2767	96
2/13/59	3886	4119	106
2/27/59	3564	3350	94
3/13/59	2125	2380	112
3/27/59	2383	2645	111
4/10/59	2088	2297	110
4/24/59	2670	2804	105
5/1/59	2737	2710	99
5/15/59	2688	2634	98
5/29/59	3210	3595	112
6/12/59	1824	2008	110
6/26/59	2156	2176	101
TOTAL	37816	39338	104
Expenditure Pattern (8 Mos.) 104%			

TABLE II—*Example of an Eight Month Expenditure Pattern for One Shop*

GENERATE MODIFIED ENGINEERED STANDARDS THROUGH WORK SAMPLING

A few years ago the determination of productive time and avoidable delay time would have been a stupendous task involving the constant observation of thousands of workers. Fortunately, today we have a simple and inexpensive device known as work sampling. By this means, observations taken on a random basis produce results which approach, within acceptable limits, the accuracy obtainable by direct observations. When the productive percentage, as derived by work sampling, is applied to a statistical time value, the product is the amount of time which would be required if the total eight hour day were devoted to work. Table III is an example of a work sample summary showing the several categories of work activity and the productive percentage used in converting to modified engineered standards.

The application of pace rating to a standard of this type (not directly observed) can be very complex. However, pace rating studies of day workers con-

	Productive						Productive Delay						Personal			Non Productive Delay							
Date	% Working	% Productive Talk	% Study Plans	% Move Equipt. on Job	% Study Job	% Process Time	% Request Assist	% Weather Delay	% Get Material	% Get Plans	% Get Tools	% Group Interference	% Personal	% Idle	% Administrative Time	% Material	% Tools or Equipment	% Plans or Work Instr.	% Job Assignment	% Assist Trade	% Supervisor	% Trade Interference	% Ships Force Interfer.	% Total Observations
4-27	53	9	3	–	1	4	–	–	–	5	–	1	11	9	2	–	–	–	–	–	–	–	–	
4-28	59	11	1	–	–	1	–	–	5	–	1	–	9	9	–	–	–	–	–	1	–	–	4	
4-29	43	7	–	–	–	1	–	–	2	2	–	–	9	13	12	–	–	–	–	2	2	6	–	
4-30	69	9	1	–	–	2	–	–	–	–	–	–	9	3	9	–	–	–	–	–	–	–	–	
5-1	86	3	–	–	–	–	–	–	–	–	–	–	8	–	6	–	–	–	–	–	–	–	–	
5-5	40	14	2	3	3	3	–	–	1	–	5	1	16	1	–	5	2	–	3	3	–	1	–	
5-6	47	15	4	–	5	5	–	–	1	–	2	3	10	2	–	–	2	–	2	2	–	2	–	
5-7	45	7	2	2	4	7	1	–	–	–	1	2	12	–	–	1	2	1	–	2	–	1	14	
5-8	42	12	6	–	3	4	2	–	3	1	2	3	12	–	–	–	–	–	2	6	–	2	1	
5-10	40	11	–	2	6	3	1	9	1	–	3	2	11	–	1	1	–	–	–	3	1	–	4	
5-11	41	15	1	4	4	6	2	–	4	–	4	6	9	–	–	1	–	–	–	4	–	–	1	
No. Of Obsvn	753	158	27	15	34	47	9	13	22	11	23	24	158	52	33	10	7	1	8	31	4	17	34	1498
% Of Total	50	9	2	1	2	3	1	1	2	1	2	2	11	4	3	1	–	–	1	2	–	1	2	
% Of Total	← 67% →						← 9% →						← 17% →			← 7% →								
		← Productive Percentage 76% →																						

TABLE III—*Work Sampling Summary Shop 41 Waterfront 4-27-59 thru 5-11-59*

An Example of a Work Sample Summary showing Productive Percentage (Rounded to nearest whole percentage)

ducted by Dr. Marvin E. Mundel, and other eminent authorities in the field of industrial engineering, provide data which indicate that the average day worker works at a pace of 65 percent. Further analysis by Dr. Mundel and the Bureau of Ships resulted in a pace selection of 75 percent as the average for production workers in shipyards. Applying this percentage to the previous product of statistical time and work sampling productive time, the result is the length of time required by a man working 100 percent of the time at 100 percent pace. Obviously, such a condition is impossible. Provisions must be made for the time required by the mechanic for personal needs. Studies in this shipyard indicate that personal time allowances of 9 percent in the shops and 14 percent on board ship are reasonable. Accordingly, the amount of time represented by these percentages is added to each pure productive standard time. The final product is a modified engineered standard. This is a synthesized full engineered standard with all factors considered except method study. Table IV shows a sample calculation for a conversion from an authoritarian to a modified engineered standard. Table V is the resulting modified engineered standard derived from the authoritarian standard shown in Table I.

TABLE IV—*An Example of the Calculation for Conversion of Authoritarian Standards to Modified Engineered Standards*

Modified Engineered Standard = A x E x W x S x (1+P)
A= Authoritarian Time Value (Fig. I)
E= Expenditure Pattern in Percent (Fig. II)
W= Productive Percentage taken from Work Sampling (Fig. III)
S= Pace Average for Shipyard = 75%
P=Personal Time Allowance (9% shopwork, 14% shipwork)
M.E. Std (Fig. V) = 100 x 1.04 x .76 x .75 x 1.14 = 68

APPLICATION OF WORK SAMPLING TO NAVAL SHIPYARD SITUATIONS

Since work sampling, or ratio delay, as it was originally called, is a fairly recent innovation in the field of work measurement, it is worthwhile to set forth a brief description of the process. Basically, it is similar to the random sampling theory used in quality control. The process consists of selecting a predetermined number of samples at random from a large group, and on the basis of their analysis, predicting the composition of the whole group. The first step in work sampling is to determine the objectives and select the categories for observation. For example, in the Boston Naval Shipyard work sampling studies, the goal is to ascertain the following: what constitutes a working day in the various shipyard areas; what part of total time is productive; what are the types and magnitudes of delay; how much personal time is being taken, etc. To accomplish this, approximately 25 categories have been selected. These are grouped into four major areas, Productive Time, Personal Time, and Productive Delay Time, and Non-Productive Delay Time. Large scale work sampling studies can be conducted twice a year. During these surveys, each of three weeks duration, 70,000 to 100,000 observations can be made. Times of observations are determined by random time tables, and the data is processed by electric accounting machines. Table III shows one of the completed work sample sheets. Table VI shows a shipyard-wide comparison summary from recent studies at Boston Naval Shipyard. The detailed procedure used in the conduct of this study is as follows:

1. Studies are made at the Leadingman gang level, selected at random.
2. Each gang is studied for five days.
3. Each observer is assigned to observe in a shop other than his own.
4. All observations are recorded on electric accounting machine (EAM) cards. Each observer is furnished with a supply of cards containing the following pre-punched information: study number, area code, shop number, trade, observer's code, shift code, and leadingman code.
5. For each observation taken, the observer is required to marksense the following information: half hour period of the day and work sample category.
6. The following machine tabulations of data are provided for analysis: daily report of observations

Tubes, Generating—1" Diameter						Prep'd.		Standard No. 41001		D3	Sheet 1 of 1				
								Rev. A			Date 3 Nov. 1958				
								App'd.							
	Shipwork					Shopwork				Shipwork						
Quantity	Burn	Flush	Shrink Back Out	Clean Holes	Handle	Bend	Cut	Mill	Polish	Stick Hold On	Roll Off Mud Drum	Roll Off Steam Drum	Mill	Reroll	Bell	Handle Clean Up
1	.034	.03	.07	.025	.017	.28	.023	.017	.023	.100	.07	.06	.08	.08	.006	.03
100	3.4	3.0	6.8	2.5	1.7	27.2	2.3	1.7	2.3	10.2	6.8	5.6	8.0	8.0	.5	2.7
200	6.8	5.6	13.6	5.0	3.4	56.0	4.7	3.5	4.7	20.4	13.6	11.4	15.8	15.8	1.1	5.4
300	10.2	8.5	20.4	7.5	5.1	84.0	7.0	5.2	7.0	30.6	20.4	17.0	23.8	23.8	1.7	8.2
400	13.6	11.4	27.2	10.0	6.8	112.	9.3	7.0	9.3	40.8	27.2	22.7	31.7	31.7	2.2	10.9
500	17.0	14.2	34.0	12.5	8.5	140.	11.7	8.7	11.7	51.0	34.0	28.4	39.7	39.7	2.9	13.6
600	20.4	17.0	40.8	15.0	10.2	168.	14.0	10.5	14.0	61.2	40.8	34.0	47.6	47.6	3.4	16.3
700	23.8	20.0	47.6	17.5	12.0	196.	16.3	12.2	16.3	71.4	47.6	39.6	55.6	55.6	3.9	19.0
800	27.2	22.7	54.4	20.0	13.6	224.	18.6	14.0	18.6	81.6	54.4	45.3	63.5	63.5	4.5	21.8
900	30.6	25.5	61.2	22.5	15.3	252.	21.0	15.7	21.0	91.8	61.2	51.0	71.4	71.4	5.1	24.5
1000	34.0	28.4	68.0	25.0	17.0	280.	23.3	17.5	23.3	102.0	68.0	56.6	78.9	78.9	5.6	27.2
1100	37.4	31.2	74.8	27.5	18.7	308.	25.6	19.2	25.6	112.2	74.8	62.3	87.	87.	6.2	29.9
1200	40.8	34.0	81.6	30.0	20.4	336.	28.0	21.0	28.0	122.4	81.6	68.	95.2	95.2	6.8	32.6
1300	44.2	37.0	88.4	32.5	22.1	364.	30.3	22.7	30.3	132.6	88.4	73.4	102.7	102.7	7.3	35.4

INSTRUCTIONS

1. For 50 tubes or less add 5 hrs. to shopwork, to shipwork removals, and to shipwork installation to cover set up and breakdown time because only a few tubes are involved.
2. Bending operation based on an average of three (3) bends per tube.

TABLE V—*An Example of Standard of Standard Data Scope and Modified Engineering Quality.*

Production Dept. Work Sampling Summary
Combined Shop Work and Waterfront (Weighted)

CATEGORY	1958 %		1959 %		Dif. %		
01 Working	48.7		51.7		+3.0		
02 Productive Talk	6.8		7.4		+0.6		
03 Study Plans	1.6	67.1	1.8	71.5	+0.2	+4.4	Productive
04 Move Equipment	1.5		1.3		−0.2		
05 Study Job	1.4		1.8		+0.4		
06 Process Time	7.1		7.5		+0.4		
08 Request Assist	0.2		0.3		+0.1		
09 Weather	0.2		0.2				
10 Get Material	4.0		4.4		+0.4		
11 Get Plans	0.2	7.0	0.2	7.1		+0.1	Productive Delay
12 Get Tools	1.7		1.4		−0.3		
13 Group Interference	0.7		0.4		−0.3		
14 Miscellaneous			0.2		+0.2		
% of TOTAL	74.1		78.6		+4.5		
21 Personal	12.1		13.1		+1.0		
22 Idle	4.2	18.6	2.9	17.1	−1.3	−1.5	
23 Administrative	2.3		1.1		−1.2		Personal
% of TOTAL	18.6		17.1		−1.5		
31 Material	0.2		0.3		+0.1		
32 Tools or Equipment	0.1		0.2		+0.1		
33 Plans or ICs							
34 Job Assignment	4.6		1.9		−2.7		
35 Assist Trade	1.2		0.7		−0.5		
36 Supervisor	0.1	7.3	0.2	4.3	+0.1	−3	Non Productive Delay
37 Trade Interference	0.4		0.4				
38 Ships Force Interfer.	0.3		0.2		−0.1		
39 Equip. Breakdown			0.2		+0.2		
40 Ship Movement	0.4		0.2		−0.2		
% of TOTAL	7.3		4.3		−3.0		

TABLE VI—*Work Sampling Comparison 1958 Vs. 1959*

by area and category, summary report of observations by shop, area, and category, summary runs by half hour period of the day and summary runs by shop, area and category.

The operating details enumerated are in use at the Boston Naval Shipyard and are recommended for use in sampling productive workers.

DEVELOP SHORT RANGE GOALS—SHOP BUDGETS

The basic tools for control of productive work and productive costs are standards of the several qualities and scope aided by the work sampling device. The expenditure of considerable effort in the accumulation of these tools is not sufficient; they must be used effectively. It is obvious that any work standard, providing it remains fixed, can serve as a valid measure of improved productivity. However, if the standard is of authoritarian or statistical quality, it is equally obvious that it will provide little or no incentive toward increasing productivity. On the other hand, the modified engineered standard which is about 25-35 percent lower provides an adequate, if distant, goal for increasing productivity. Experience indicates that large industrial operations are slow to change and that the attainment of a 25 percent improvement in productivity cannot be made overnight. The action that is necessary to accomplish a productivity gain of this magnitude is largely in the hands of management and includes as most important steps, the elimination of delay time and the reduction in situations which generate delay time by improvements in work assignments and work planning. Significant in this category are waiting (for tools, assist trades, supervisor's instructions, material and plans) and interference (by other trades, ship's force and ship movements). These delays are indicated in Tables III and VI as Productive Delay and Non-Productive Delay. Elimination of these conditions must be undertaken by management action in positive and progressively improving steps. To provide a guide for the improvement of productivity in quickly attainable steps, it is necessary to devise an intermediate goal which is itself quickly attainable. This goal may take the form of a shop work budget which bears a specific relationship to the modified engineered standard estimates for work.

Figure 1 shows the relationship among the several qualities of standards and a shop work budget. The factor used to compute the shop work budget should be agreed upon by management as being attainable within the immediate future, and it should be the subject of renegotiation about twice a year. The modified engineered standard estimates remain the long range productivity goal, while the shop work budget is the short range goal.

The computation of a shop work budget is easily computerized by storing the shop budget factors in the computer. The standard estimates are coded for scope and quality and submitted on EAM cards as previously described. The computer then determines the budget for each estimate, based on individual shop factors, and summarizes for each project. It is desirable to operate a shop work budget with respect to individual projects so that performance can be evaluated periodically as the projects complete. With this in mind, the Boston Naval Shipyard operates its shop work budget on the basis of customer orders, consisting primarily of ship overhauls. Using the gross approach described above, it is particularly unfair to make judgments on individual items of work; however, when a total ship overhaul is summarized, considerable maneuvering room is obtained for indi-

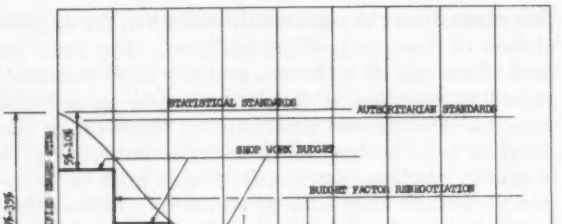


Figure 1. Relationship of Standards, Expenditures and Shop Work Budgets.

vidual items of work (some of which will no doubt be over estimated and some of which will be under estimated). Judgments, made on the basis of summarized shop work budgets and summarized expenditure for total projects, are valid with respect to overall improvements in productivity.

The continuity and durability of the program are contingent upon the periodic renegotiation of the shop work budget factors, and upon the periodic conduct of work samples. These two devices provide information as to the rate at which increased productivity is closing the gap on the modified engineered standards without requiring any adjustment in the modified engineered standards themselves.

PROGRAM OF CONTINUING REFINEMENT OF INITIAL GROSS APPROACH

It is recommended that modified engineered standards be the subject of redetermination based on return costs and on work samples to determine the average productive percentage at two year intervals. The actual work of producing a refined set of modified engineered standards should be in process during all of the two year period; however, the cutover to the use of the newly determined standards should be a general yard-wide cutover rather than individual shop or item cutover. The purpose of this generalized cutover is to maintain knowledge of progress toward improved productivity, and to maintain yard-wide uniformity in incentive and work requirements.

In the effort described above, it should be noted that in almost every case a gross approach is advocated. Some justification of this is in order. It is the writers' contention that, while improvements in productivity in the order of magnitude of 25-35 percent are in process, attempts to gain knowledge of individual item standards to a very refined degree will prove excessively cumbersome, and the whole program will be defeated by an overwhelming number of details. The details, in the aggregate, will not produce any better information than is provided by the advocated gross approach. However, after several readjustments of modified engineered standards have been made, the work samples should indicate that delay time is reduced to the point where not more than 4 percent or 5 percent gain in productivity is attainable. At this time it will be necessary to resort to a detailed approach in order to pinpoint the particular work items that are causing the remaining delay time and the individual items upon which productivity can be improved.

USE COMPUTER TO DEVELOP EXCEPTION REPORTS

For a refinement of standards, using the detailed approach, it will be necessary to develop a computer program to analyze individual standard data items, and to promote exception reports which will indicate those items which require refinement. This computer program must use the standard data items as the basis for exception. Therefore, it will be imperative that the computer program be used to compute and summarize the standard data estimates at work levels normally used by the several shops. We are confident that this can be accomplished with the electronic data processing machines that are in current use by most shipyards. We visualize that the computer will do a large proportion of the work now being done manually, e.g., computer job estimates from standard data, and the printing of work instructions based on standardized terminology. It is anticipated that individual shops will require individual programs; and possibly that the areas or trades within a shop will require separate computer programs in order that the programs be simplified insofar as possible.

ENGINEERED STANDARDS

The development of work standards of the engineered quality is by definition a detailed procedure, since it must apply to a specific job and a specific method of doing the job. This type of standard is not susceptible to the gross approach advocated above. The engineered standard, however, is very valuable for work which is repetitive. The decision to engineer a standard for a particular work item must be based upon the cost of engineering the standard, the repetitive nature of work, and the anticipated savings. It should be noted that future development of standard data tables of engineered quality is possible. However, for the present, more significant gains are attainable by taking advantage of modified engineered standards for most of the job shop work, and by the judicious application of engineered standards only to those operations where large tangible improvements are obviously possible.

DEVELOP JOB STANDARDS FOR REPETITIVE WORK

In the same manner that the preceding program is continuous and durable in the improvement of standards' quality, a program can be developed for the increase in scope of classification of standards. Stand-

ard data tables are valuable since they are the building blocks for all work accomplished in a shipyard. However, the cost of recomputing each job instruction standard estimate every time it is used is prohibitive. Until a mechanized program such as previously described is developed, a manual program should be used whereby a job instruction, once estimated, will remain on file for future reference. Within a brief period the repetitive job instructions will be recognized, segregated, pre-printed, and filed for future use. In the same manner, with an adequate file system, whole repetitive jobs can be identified, preprinted, and filed for future use. The end result of such a process is that a total repetitive job order can be standardized by the accumulation of pre-printed job standards from each shop and the assembly of these into a job order standard. Since the estimates were originally derived from the basic standard data tables, these operations standards, job standards, and job order standards are valid work standards of the same quality as the original standard data.

MANAGEMENT'S PART IN THE APPLICATION OF A CONTROL PROGRAM

The foregoing has described the method required for the development of work standards, for their improvement in quality and scope, and for their use in the control of productive work. The usefulness of these devices to the industrial organization is completely dependent upon management. A fully developed set of work standards, of modified engineered quality, provides management with an invariable productivity goal. It is not affected by variations in wage rates or inconsistencies among estimators. It constitutes a reference base against which improved productivity can be measured and evaluated. It is no longer necessary to resort to job price comparisons among shipyards with the inevitable indeterminate and inconsistent variables of facilities, material procurement cost, and scope of work actually accomplished.

In an industrial activity where incentive pay is *not* contemplated, the effectiveness of a work standards program in improving productivity is particularly dependent upon the attitude of all levels of management.

The use and enforcement of work standards of the productivity goal type have the beneficial effect of making inefficient production methods and procedures intolerable. Productive workers and their supervisors will force management decisions in the areas which will permit the completion of productive work within standard estimates. However, management must be receptive to these pressures as requirements on their performance, and not as productive worker excuses for a lack of conformity with work standards.

Management must get back into the business of indicating the performance required by its industrial organization. This can be accomplished by assuming the responsibility for development of work standards, and by controlling their development and use. The organization whose performance is being measured should not be responsible for determining the yardstick to be used in any measurement area, whether it be standards development or work sampling. Any measurement should be accomplished by management levels whose productivity is not being measured.

Without management enforcement of, and response to, a work measurement—work standards program, the large amount of work involved in the development of standards is wasted. Before embarking on such a program, management should determine its willingness to undertake an active and decisive part in the program. Management's part should be the larger part of such a program; and all levels of management should be prepared to improve their performance by:

1. Improving work planning
2. Improving stabilization of workload
3. Improving availability of plans, material and tools
4. Eliminating interference from other trades, ship force, shop movements
5. Requiring progress reports on performance
6. Insisting on progress toward improved productivity
7. Judging performance based upon comparisons of standard estimates vs mandays expended
8. Enforcing the use of standards
9. Instituting review procedures to ensure the proper use of standards in making estimates

Too frequently industrial activities have been driven toward improved productivity only in connection with special projects or by force of individual personality. In these cases, where a basic program is lacking, the improvements made are not permanent. On the other hand the procedures described herein, if supported by management, are sure to produce steady and enduring gains, and provide the means with which such gains can be measured.

SUMMARY

The program as described is directed toward improving productivity of individual workers by identifying and eliminating those problems which prevent sincere efforts of productive workers. It is based upon the fact that management must indicate the type of productivity that it desires in specific terms. The program is realistic in that useable standards are developed early with a view toward their improvement in quality and scope with use and in that intermediate, as well as long range, attainable productivity goals are provided. All types of industrial activities are susceptible to improved productivity through the recommended program, regardless of the size of the activity or the degree to which repetitive work is accomplished.

BIBLIOGRAPHY

Title	Author	Publisher
How to Chart Timestudy Data	Phil Carroll	McGraw-Hill Book Co.
Business Statistics	Riggleman & Frisbee	McGraw-Hill Book Co.
Production Forecasting, Planning & Control	E. H. MacNiece (2nd Edition)	John Wiley & Sons, Inc.
Work, Workers, and Work Measurement	Adam Abruzzi	Columbia University Press
The Gantt Chart	Wallace Clark (3rd Edition)	Sir Isaac Pitman & Sons
Time Study for Cost Control	Phil Carroll (3rd Edition)	McGraw-Hill Book Co.
Production Handbook	L. P. Alford & J. Bangs	Ronald Press Co.
Plant Engineering Handbook	William Staniar	McGraw-Hill Book Co.
Time Study Manual	Stanley O. Robinson	Northeastern University
Production Control	William Voris	Richard D. Irwin. Inc.
Work Simplification	Gerald Nadler	McGraw-Hill Book Co.
Production Planning & Control	Thomas M. Landy	McGraw-Hill Book Co.
Motion & Time Study	Ralph M. Barnes (4th Edition)	John Wiley & Sons, Inc.
Motion & Time Study	Marvin E. Mundel (2nd Edition)	Prentice-Hall, Inc.
Basic Motion Time Study	G. B. Bailey & Ralph Presgrave	McGraw-Hill Book Co.
Engineered Work Measurement	D. W. Karger & F. H. Bayha	The Industrial Press
How Foremen Can Control Costs	Phil Carroll (1st Edition)	McGraw-Hill Book Co.
Timestudy Fundamentals & Foremen	Phil Carroll (2nd Edition)	McGraw-Hill Book Co.
Work Sampling	Ralph M. Barnes (2nd Edition)	John Wiley & Sons, Inc.
Work Sampling	R. E. Heiland & W. J. Richardson	McGraw-Hill Book Co.
Basic Statistics	George Simpson & Fritz Kafka	W. W. Norton & Co.
Introduction to Work Study	International Labour Office	Atar, Geneva, Switzerland
Industrial Eng. Handbook	H. B. Maynard	McGraw-Hill Book Co.

RADICAL POWER, ANYONE?—Energy Conversion Laboratories announces development of "an entirely new method of producing electricity, capturing the instantaneous energy of free radicals and converting it to useful forms of power." The firm's founder, Stanford R. Ovshinsky says, without revealing details of his invention, that basic principles have been successfully and repeatedly demonstrated in the laboratory . . . that constant streams of radicals are being produced in a safe, simple, seemingly self-sustaining system; their reactions controlled at near room temperature, their energy converted directly into electricity and other forms of power.

Research/Development, September 1960

SOVIET ATOMIC ICEBREAKER *LENIN*

Completed in September, 1959 the Russian icebreaker ***Lenin***, of 16,000 tons displacement, 44,000 shp, is the first operational merchant-type ship driven by nuclear power. The propelling plant consists of three, individually operated, nuclear reactors of the pressurized type, one of which is reversible. Steam is used to drive 11,000 hp single-flow turbines which turn 8 D.C. generators through reduction gearing. Current is supplied to three main drive motors, the center one of 9800 hp, the wing motors of 4900 hp each. The three propellers are capable of driving the ship at 18 knots in open water and at 2 knots in ice 7.10 ft. thick. The main object in the construction of the ***Lenin***, apart from the propaganda value of the vessel, was to keep the Northern Sea Route open for longer periods each year. Despite the powerful icebreakers heretofore employed, the Soviet Government has not been able to maintain an open passage from Europe to Asia through the Arctic seas. Operations have come to an end usually in the early fall of the year, when the young ice forms, and it is hoped that the ***Lenin***, thanks to its strength, will be able to allow transport ships to leave the Arctic seas at a later date and thus augment the volume of cargo brought to Europe from the frozen regions.

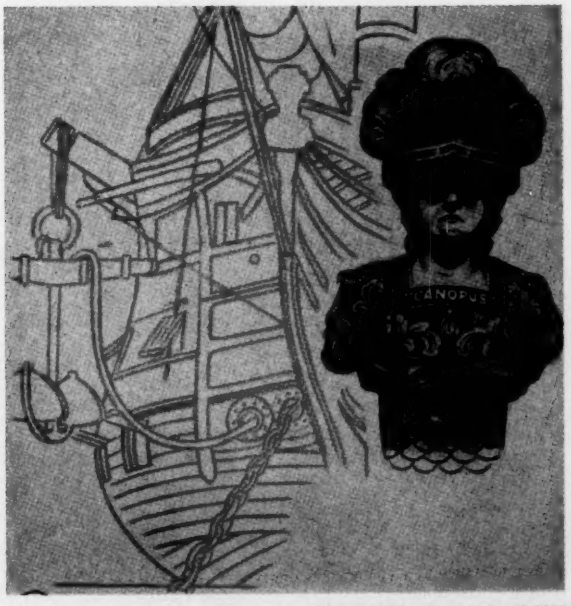
—Marine Journal, July 1960

"Ship via Hamburg," April 1960

The charm-mythical yet full of life- of a figure-head is still alive in this bow decoration of a Danish schooner of 1875. The ancient Grecian legend of nymphs of the springs, rivers and lakes, the Naiads, has given the motif to this carving.

"Ship via Hamburg," April 1960

Who could maintain that the Americans have no feeling for the romantic. This powerful "Mohawk" ruled the storms under the bowsprit of an American frigate (1816).

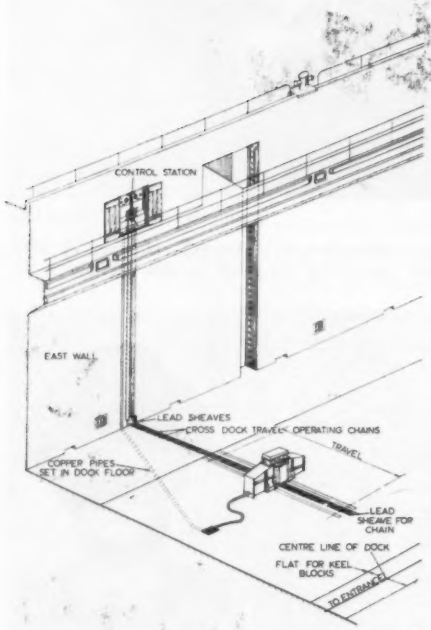


"Ship via Hamburg," April 1960

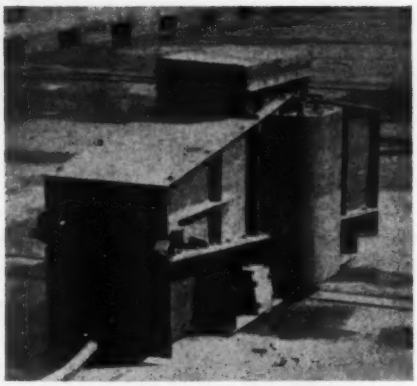
Canopus, the most prominent fixed star of the southern sky, is symbolized by this figure-head bust. It was carved in France in 1796 at a sculptor's school belonging to a shipyard.

An important feature of the new Queen Elizabeth drydock at the ship repair yard of Silley, Cox and Co., Ltd., Falmouth, is the installation of remotely controlled mechanical bilge blocks. To date over 100 large ships including the 50,000-ton d.w.c. tanker ***British Queen*** have already been docked using these blocks. Capable of being traversed across the dock floor on each side and, in addition, raised or lowered under water to suit the beam and rise of floor, the units eliminate the need for conventional side shores and thus give a clear space between the ship and the dock wall.

The blocks may be positioned under water according to the vessel's docking and lines plans and all movements are carried out and remotely controlled by the use of pneumatic and hydraulic equipment. Designed to sustain a very high compressive loading, the units are self-locking and consist of three main parts, the base, wedge and top block. A total of 34 blocks have been installed, 17 on each side, and are equally spaced along the dock floor and this arrangement affords the necessary support for the largest ships which can be docked, including tankers of up to 85,000 tons d.w.c.



Diagrammatic arrangement of bilge block control gear.



One of the bilge blocks on the floor of the Queen Elizabeth drydock.

Traversing movement is effected by a geared winch at the control station via gypsy-operated chains running in recesses in the dock walls and floor and the lateral position of the block is shown by an indicator on the winch. Vertical height indication is transmitted to the control panel by hydraulic electric pressure switches operating colored lights and the actual distance which the block has elevated is indicated by a hydraulic gauge calibrated in eighths of an inch. A separate control station is provided for each of the blocks.

It is evident that, in this case, the design of the bilge block control gear was closely related to that of the dock as a whole, but there is no reason why a similar arrangement could not be adopted to suit any existing drydock with certain modifications in layout. —THE MOTOR SHIP August 1960

THE UNITED STATES NAVY

GUARDIAN OF OUR COUNTRY

The United States Navy is responsible for maintaining control of the sea and is a ready force on watch at home and overseas, capable of strong action to preserve the peace or of instant offensive action to win in war.

It is upon the maintenance of this control that our country's glorious future depends; the United States Navy exists to make it so.

WE SERVE WITH HONOR

Tradition, valor, and victory are the Navy's heritage from the past. To these may be added dedication, discipline, and vigilance as the watchwords of the present and the future.

At home or on distant stations we serve with pride, confident in the respect of our country, our shipmates, and our families.

Our responsibilities sober us; our adversities strengthen us.
Service to God and Country is our special privilege. We serve with honor.

THE FUTURE OF THE NAVY

The Navy will always employ new weapons, new techniques, and greater power to protect and defend the United States on the sea, under the sea, and in the air.

Now and in the future, control of the sea gives the United States her greatest advantage for the maintenance of peace and for victory in war.

Mobility, surprise, dispersal, and offensive power are the keynotes of the new Navy. The roots of the Navy lie in a strong belief in the future, in continued dedication to our tasks, and in reflection on our heritage from the past.

Never have our opportunities and our responsibilities been greater.

DE LAVAL propulsion u
power U.S.S. PREBLE ... s

Successfully meets performance standards in trials

Second of the new class of guided-missile frigates, the U.S.S. PREBLE (DLG-15) is powered by two De Laval cross compound main propulsion turbine units and reduction gears. In addition, De Laval manufactured and supplied four turbine-driven fuel oil service pumps, two turbine-driven and two motor-driven lube oil pumps, port fuel oil pumps, diesel oil transfer and fuel oil transfer pumps.

The U.S.S. DEWEY (DLG-14), now at sea, is powered by De Laval main propulsion and auxiliary units. De Laval has also been chosen to supply the main turbines and gears and auxiliary equipment for seven additional DLG class vessels.

DL228

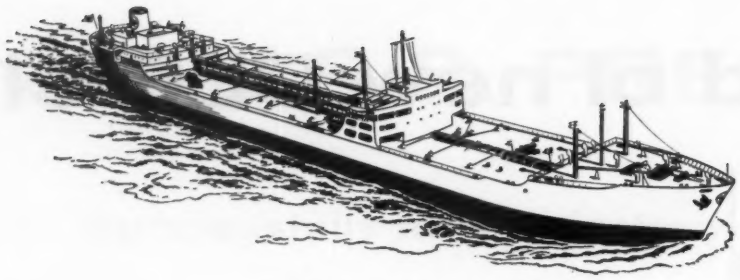
...units

...second of new DLG class

Built at the Bath Iron Works, Bath, Maine, the 512 foot, 5,600 ton U.S.S. PREBLE was commissioned on May 9, 1960 at the Boston Naval Shipyard

DE LAVAL *Steam Turbine Company*

NOTTINGHAM WAY, TRENTON 2, N. J.

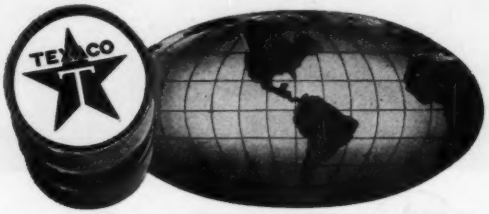


Now available around the world

TEXACO BUNKERING SERVICE

Newly expanded bunkering service, on a world-wide basis, now enables Texaco to serve your vessels even better.

There is a complete line of Texaco Marine Products—lubricants, fuels and protective coatings for all types of vessels. These, combined with famous Texaco engineering and delivery service, are potent factors in assuring dependable, efficient, low cost operation. Texaco Inc., *Marine Sales and Bunkering Services Division,* 135 East 42nd Street, New York 17, New York.



QUALITY AND SERVICE AROUND THE WORLD

"THE SHIPBUILDER AND MARINE ENGINE BUILDER"

EXTREME-PRESSURE LUBRICANTS FOR MARINE GEARS

ACKNOWLEDGMENT

This article, by A. D. Newman, appeared in the Annual International Number of "The Shipbuilder and Marine Engine-Builder" of April 1960, from which it is reprinted. It was originally presented to the Institution of Mechanical Engineers.

THERE APPEAR TO BE three main reasons, not necessarily unrelated, for using extreme-pressure lubricants in marine gearing, and it is worthwhile examining them in some detail, since they do not lead to quite the same requirement in the lubricant. The three are:—

(1) An extreme-pressure oil may be used where the design *per se* requires a higher load-carrying capacity than that provided by a normal oil.

(2) Such an oil may also be used where the design does not of itself warrant the use of an extreme-pressure oil but where its use will afford a degree of insurance against trouble.

(3) An extreme-pressure oil may be employed to allow the use of gear materials, which, giving advantages in other respects, would be prone to trouble if a plain oil were used.

The first reason, that of straightforward design requirement, was the one which led to the original development of marine geared-turbine extreme-pressure oils in Britain. It occurs where the loading and/or speed conditions are so difficult that, even with extremely well-designed and accurately manufactured gears, oil-film failure will occur between the gear teeth when a plain oil is used.

The second reason applies essentially to merchant-ship gearing, where nominal loading, although it has steadily increased over the past few years, is not yet, in general, high. In this case, the nominal conditions do not appear to be above the capacity of a plain oil, but, temporarily, conditions may arise which cause trouble, perhaps only in the very early life of the machinery, and the use of an extreme-pressure oil may give the extra factor of safety temporarily required.

The third reason, that of material incompatibility, is one which has not arisen frequently in Britain in the past, though it may well do so in the future. As in many other features of design, there are compromises to be made in the choice of materials for gears, and one is between the strength and durability of the materials in the form of gear teeth and their compatibility in combination. This arises particularly with through-hardened materials, which form the bulk of those used for naval and merchant-ship gears at present; strength considerations appear to indicate that the ultimate load-carrying capacity of such gears will be obtained by a combination of alloy steels rather than the alloy-steel/carbon-steel combinations in common use

now, and some gears have been designed on this basis. In general, however, lubrication trouble has been experienced when a plain oil has been used, and it has been demonstrated in full-scale gear tests and in disc tests that the material combination has largely been the reason for this, and that the use of an extreme-pressure oil may allow the advantages of the material combination to be regained.

CONDITIONS IN MARINE GEARING

The oil must normally lubricate and cool the gears and their bearings, the turbine bearings and the main thrust bearing, in contact with ferrous and non-ferrous metals under conditions where oxidation, foaming and emulsification of the oil, and rusting and corrosion of metal parts will tend to occur and against which the oil must, if possible, be proof; this is the basic requirement of any geared-turbine oil.

Full-scale trials have been carried out by Pametrada on single-reduction, double-helical (and therefore symmetrical), short face width (and therefore relatively deflection-free) gears of marine type, having the particulars stated in Table I.

TABLE I

Center distance	35.8076 inches
Face width	5 in. (+3-inch gap).
Hob	6/10 inch axial pitch; 16 deg. flank angle.
No. of teeth	41 (pinions), 284(wheels),
Addendum/dedendum	60/40 (pinions).
Helix angle	29 deg. 58.805 min.
Maximum speed	6,000 (pinions); 866 (wheels).
Maximum pitch-line speed	236 fps
Maximum rolling velocity (pitch point)	74.5 fps
Maximum sliding velocity (pinion tip/wheel root)	43.2 fps
Maximum sliding velocity (pinion root/wheel tip)	33.3 fps
Slide/roll ratio (pinion tip/wheel root)	0.627
Slide/roll ratio (pinion root/wheel tip)	0.735

The following general relevant results were obtained in all cases when running on a plain mineral oil:—

Scuffing occurred at reduced speeds at tooth loadings which had been accepted satisfactorily at higher speeds. (For example, a 3½ per cent nickel steel pinion running against a 0.3 per cent carbon-steel wheel scuffed at just under half full-speed, and a 4 per cent nickel-chrominum-molybdenum steel pinion running against a 3 per cent nickel-chromium-molybdenum steel wheel scuffed at about ⅛ full speed; incidentally, at about 70 per cent of the tooth loading of the 3½ per cent nickel steel-0.3 per cent carbon steel combination.)

Scuffing occurred more readily when the gears were overrunning, that is, wheel driving pinion.

The scuffing on the tooth surfaces did not appear to originate at the ends of contact, that is, at the combination of maximum sliding speed and slide/roll ratio, but considerably nearer the pitch point.

If these findings, which appear to be inherent properties of the gears, are taken in conjunction with the operating conditions of marine gears, it will readily be seen that high-load high-speed performance is not the most important requirement of a generally applicable extreme-pressure oil. It should also be observed that one of the times in the life of a set of marine gears when the maneuvering sequence is always carried out is during the trials, when the gears may have only run for a few hours under load previously and are therefore practically "raw." The preponderance of scuffing troubles during trials, the fact that most of it has been on secondary gears, the reasonable certainty in many cases that it occurred during maneuvering, and the surprising (in proportion to the total number of incidents) number of instances where scuffing has occurred on the astern tooth flanks, all indicate where and when the most difficult conditions occur.

DEVELOPMENT OF EXTREME-PRESSURE OILS FOR MARINE GEARED TURBINES

Technical development of extreme-pressure oils for marine geared turbines has already been reported in detail and from the suppliers' points of view. It is relevant now to examine the criteria to which the development is aimed, and it is proposed to restrict this mainly to the aspect of load-carrying capacity.

The original aim was to produce lubricants suitable for naval vessels with advanced geared steam-turbine machinery, in which the gearing was to be surface-hardened and ground and to transmit loads much greater than those in the then conventional gears. The Admiralty specification for this type of lubricant was based on the existing OM-100 specification, with the addition of a load-carrying capacity requirement and a compatibility clause. The OM-100 specification covered a conventional geared steam-turbine oil containing oxidation, rusting and foaming inhibitors, and included viscosity and viscosity index, flash point, pour point, acidity, corrosion, foaming and demulsification requirements. The load-carrying requirement for the new specification was stated in terms of the Institute of Automobile Engineers (I.A.E.) 3¼-in. centers gear machine, mainly on the reasonable basis that the test specimens were surface hardened and ground gears and that a very large amount of experience existed with this machine.

The I.A.E. machine is a spur-gear power-circulator, torque being applied to the system by a split

coupling and loading lever, the torque being defined, on a standard loading lever, by the load applied. The gears are carburized, hardened and ground 2 per cent nickel-molybdenum (En 34) steel, of short face width, 26 degrees 19 minutes working pressure angle, 4.769 diametral pitch, 15/16 teeth. The specification, designated OEP-90, requires a mean minimum lever load for scuffing of 90 lb (equivalent to a nominal tooth loading of 5,500 lb per in.) at 4,000 rpm and an oil inlet temperature of 70°C. This represents a load-carrying capacity about 2½ times that of OM-100.

So far, this is the only specification in Britain for a marine turbine extreme-pressure lubricant, and most of the oils of this type, though developed in the load-carrying capacity sense in detail through a number of different tests, such as those in four-ball and in disc test machines, have been evaluated for acceptance against the OEP-90 specification.

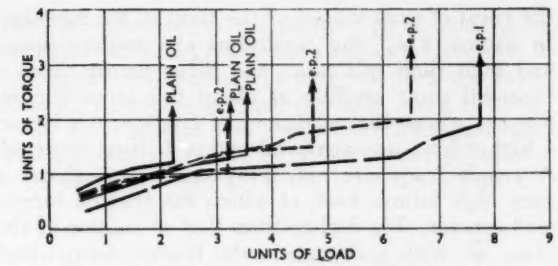
A number of extreme-pressure oils which have been submitted for use in particular merchant ships have been tested by Pametrada on behalf of the engine-builder involved, whether or not they had been evaluated by the OEP-90 specification test. In each case, a disc machine was used, in which specimens of the correct material combination were run together over a range of slide/roll and speed conditions.

OPERATION OF EXTREME-PRESSURE LUBRICANTS

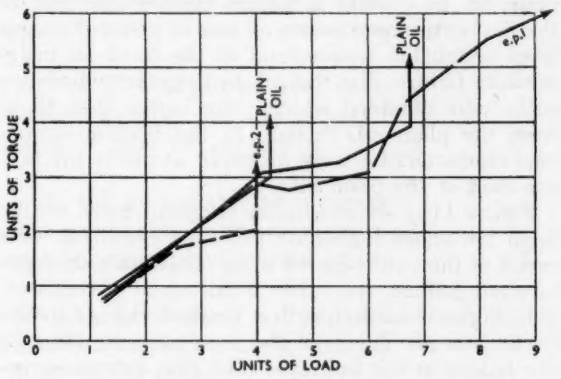
The phenomenon of scuffing is one which causes much discussion and difference of opinion. One reason for this is that differences in both effect and cause are involved in the concept of scuffing; effect, in that the term is used to cover degrees and types of damage for which general agreement has not been reached, and cause, because even in the simplest practical case there are at least two interdependent systems involved, those of oil film breakdown and of surface film, surface or material failure. When an extreme-pressure lubricant is involved the position is further complicated, since aspects of both cause and effect are materially altered. It is obvious, therefore, that an investigation of scuffing must consider the developing process leading up to scuffing and not only the failure and failure conditions themselves.

The results which follow, although typical, are particular ones, intended to illustrate particular points only, since no generally applicable relationships between the variables have yet been established. In each case, the discs were of 2½ per cent nickel-chromium-molybdenum steel (En 25) running against 0.4 per cent carbon steel (En 8), a typical marine pinion/wheel combination.

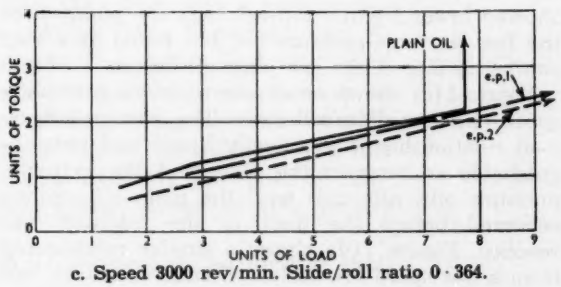
Figure 1 shows friction results in terms of driving torque for various oils, at constant speeds and slide/roll ratios with steadily increasing load to



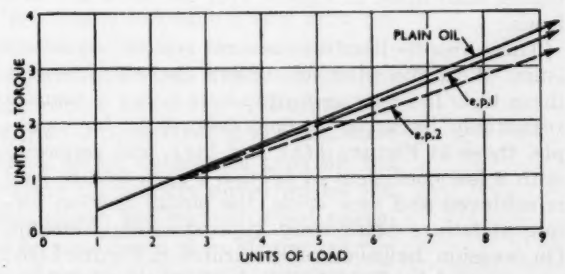
a. Speed 3000 rev/min. Slide/roll ratio 1 · 192.



b. Speed 500 rev/min. Slide/roll ratio 1 · 192.



c. Speed 3000 rev/min. Slide/roll ratio 0 · 364.



d. Speed 500 rev/min. Slide/roll ratio 0 · 364.

Figure 1. Friction Results in Terms of Driving Torque for Various Oils.

the point of final failure or the limit of the machine. In Figure 1(a), the conditions are medium-speed and high slide/roll ratio, and three results from a plain oil show scuffing at about the same friction torque; where the coefficient of friction was lower, a higher load was achieved before failure occurred. A result from one extreme-pressure oil shows a very high failure load, at which the friction torque was considerably higher than that at failure of the plain oil, with a change in the friction-torque-load characteristic at about the failure load of the plain oil. Three results from a second extreme-pressure oil show in one instance a failure to that of the plain oil, in another a failure approaching that of the first extreme-pressure oil and at about the same level of friction torque, and in the third an intermediate failure. For this oil, in the cases where results were obtained which were better than those from the plain oil, changes in the friction-torque-load characteristic were observed at about the failure load of the plain oil.

Figure 1(b) shows similar friction-torque results for a low-speed high-slide/roll ratio condition. One result of the two from the plain oil shows a straightforward failure, the other a failure at a considerably higher load but with a marked change in the friction-torque curve in the area corresponding to the failure in the first case. The first extreme-pressure oil did not fail at the limiting load of the machine, but showed distinct changes in friction characteristic in areas corresponding to the two plain-oil failures. The second extreme-pressure oil showed lower friction torques than the plain oil or the first extreme-pressure oil, but failed at a load similar to that of the low plain-oil failure.

Figure 1(c) shows results for a condition of high-speed and low-slide/roll ratio. The friction-torque-load relationship is practically linear and indistinguishable as between the plain and the extreme-pressure oils, although with the plain oil scuffing occurred before the limit of the machine was reached. Figure 1(d) shows a similar relationship from a low-speed low-slide/roll ratio condition, but it should be noted that the friction torques are higher than those in Figure 1(c) for corresponding loads.

These results illustrate several typical characteristics. With the plain oil under the conditions in these tests the friction-torque-load curve is usually reasonably linear up to final failure, as, for example, those in Figures 1(a) and 1(c), and generally with a low coefficient of friction a high failure load is achieved and *vice versa*, the actual friction torque at failure being very approximately constant. On occasion, however, as illustrated in Figure 1(b), two distinct levels of failure load are seen, with an indication of change in the friction curve leading to the higher failure load in the area of the lower failure load. These results suggest that with a plain oil the failure generally has a primary cause, probably that of oil film failure, leading immediately to the effect of scuffing and that this is governed by the rate at which the film will accept energy without breakdown; on occasion, however, this does not lead immediately to scuffing and it appears that some other system comes into play.

With some extreme-pressure oils, the part of the friction-torque-load curve below the failure load of the plain oil is practically identical with that of the plain oil; but above the failure load of the plain oil the extreme-pressure oil appears to exhibit the action of another system, which it is suggested is one of surface-protective films, which eventually break down at a much higher load and incidentally at a much higher rate of energy input. In some cases with such oils, especially at low speeds, this second system does not appear to come into play, and failure occurs at a level similar to that of the plain oil.

With other extreme-pressure oils, the friction torque appears distinctly lower than that with the plain oil as the failure load for the plain oil is reached, and often a final failure load is achieved which is considerably greater than that obtained with the plain oil. It is interesting to note that in many cases, however, the friction torque at failure is similar to that of the plain oil. In other cases, however, again particularly at low speeds, although the friction-torque level is relatively low, failure occurs at a load similar to or lower than that achieved by the plain oil.

FUTURE REQUIREMENTS

Present merchant-ship gear designs in general combine alloy-steel pinions with carbon-steel wheels, and the limit of this type of gear has probably almost been reached with gears having K factors between 100 and 110 now at sea. The trend towards larger tankers, though not in itself necessarily increasing gear nominal loading, may increase maneuvering loads, and the cost of a prolonged running-in period increases. The use of extreme-pressure oils for the initial charge in such machinery appears established therefore, since it allows rapid bedding of the gears by protecting high spots against scuffing long enough for them to be demolished by wear or deformation.

Increase on this level of loading appears bound to occur, to achieve smaller and lighter gears, and this requires enhancement of the resistance to surface fatigue and bending fatigue of the gear materials, particularly that of the wheels. It is likely that the generally acceptable limit of such properties in carbon steels has been reached, so that further improvement must be gained by using alloy steels for wheel rims or finally by surface-hardening processes. Troubles have been experienced with alloy steel combinations, which, so far as scuffing is concerned, in general, have been overcome by the use of extreme-pressure oils. Apart from the apparent lack of compatibility of some alloy steel combinations when a plain oil is used, relatively high yield

stress/ultimate tensile strength ratios occur with some such steels, which means that high spots will tend to pit before they deform or wear. Extreme-pressure oils which can overcome the lack of compatibility, and also allow such spots to wear rapidly without scuffing, are therefore required.

The final stage, that of using surface-hardened gears, involves the use of small gears and high loads in order to be competitive economically for merchant ships, and therefore appears to return to the simple requirement of extreme-pressure lubricants of high load-carrying capacity, since running-in effects are much less than with softer gears and combinations of surface-hardened materials appear to be very favorable from the lubrication aspect.

The space craft that will carry an instrumented package to the moon as part of the National Aeronautics and Space Administration's lunar study program will have solar energy converters with one-third greater efficiency than those used in previous space probes, it was revealed today by Hoffman Electronics Corporation.

There will be 12 panels mounting a total of 50,000 silicon solar cells. The cells will have an average light-to-electricity conversion efficiency of 12 per cent. Maximum conversion efficiency of solar converters on U. S. satellites now in orbit is 9 per cent.

Each solar panel for the lunar space craft will be capable of a power output of 95 watts. This is far more than the power requirements of previous space probes, according to Z. W. Pique, vice president-marketing for Hoffman's Semiconductor Division.

The solar energy converters used in NASA's lunar study will provide the power for a television camera system and other instruments that will transmit data back to earth during the flight to the moon.

FARTHER FATHOMS—Submersibles can be propelled to "depths previously considered impossible," up to 7,000 feet, with a new underwater propulsion system developed by Avien, Inc., President Leo A. Weiss of the Woodside, N. Y., firm reports. The system features use of an exhaust gas compressor capable of operating under pressures of up to 3200 psi, solving the problem of reduced engine performance due to back pressure, Weiss says. A second major factor, he explains, is a fuel pump that can operate with corrosive fuels or oxidants, the types of combinations that have the attraction of high energy potential with greatly reduced vehicle weight and volume.

—Research/Development, September 1960

"CAT'S EYES" FOR FROGMEN—Particularly valuable under zero visibility in dark or murky water, says Stromberg-Carlson, division of General Dynamics Corp., is economical new hand-held sonar equipment it has developed jointly with U. S. Navy Electronics Laboratory. Designated AN/PQS-1, the device is slightly larger than a basketball, one cubic foot in volume; has aluminum casing with hand grips. Earphones provide the underwater operator with audio information on objects detected by the searching sonar beam. Standard batteries power the transistorized portable object locator—a feature expected to save more than 90 per cent in battery replacement costs. Battery life of up to 40 hours is anticipated, due to low power requirements of transistorized circuitry. Ten prototypes will be delivered this year under Bureau of Ships contract.

—Research/Development, August 1960

The challenge of silence

The wide and deep sea is a near-perfect hiding place . . . and an infinitely mobile missile launching pad. This makes anti-submarine warfare a high-priority defense problem.

Not just the sea, but the surface and the air as well, comprise the theatre of ASW. And in all these areas, Sperry is making advanced contributions: submarine sonar detection gear . . . submarine fire control systems . . . submarine depth and maneuvering controls . . . countermeasures and counter-countermeasures . . . sophisticated navigational computers for helicopters, capable of programming a systematically precise sub search . . . automatic flight controls for the helicopter to permit it to do its job despite the vagaries of weather or mission complexity . . . for surface ships, precision torpedo fire control and hydrofoil stabilization and control systems.

Most of today's ASW programs utilize sound radiation techniques. But being explored are myriad "unsound" techniques of sea-hunting, vast new frontier for scientist and engineer . . . investigations in the electro-magnetic spectrum . . . development of advanced transducers, data processors, and means of displaying data that is gathered.

These anti-submarine warfare programs, ranging through the three dimensions of our environment, typify the *integrated* capability of the Sperry organization today. General offices, Great Neck, N. Y.

SEA • SURFACE • AIR • SPACE

SPERRY

PAUL N. GARAY

A NEW CONCEPT FOR A NUCLEAR POWER MARINE PROPULSION PLANT

THE AUTHOR

is presently with the Gas Cooled Power Group of Kaiser Engineers, Oakland, Calif. For the past several years he has been associated with the design of nuclear power plants.

He received his engineering degree in 1941 from Northwestern University. During World War II, and the Korean War, he was an Engineering Duty officer with the U.S. Navy.

His numerous articles concerning the operation and design of power and nuclear facilities have been published in various technical journals.

RECENT STUDIES which have been made in connection with the development of mobile and marine power plants indicate a wide field of application for a compact, effective power plant using a nuclear fission heat source. Suggested designs to date have included boiling water plants, steam cooled reactors, pressurized water systems, and direct cycle gas cooled reactor power systems. All these proposals require extensive compromise between the desired criteria and the practical application.

The requirements of conventional power plants for mobile and marine use are well understood. These requirements, when incorporated in nuclear concepts, must of necessity be modified for several reasons: (1) containment requirements; (2) shielding requirements; (3) specialized techniques required for maintenance and refueling; (4) limitations governing the disposal of solid wastes, and the discharge of liquid or gaseous effluents; (5) environmental hazards; (6) the economic necessity for continuous operation, with minimum time allowed for overhaul and maintenance. The resultant nuclear power plant is bulky, expensive, and demands the attentions of highly specialized personnel. Altogether, it is a special purpose plant, the use of which is justified only under very specific conditions.

The nuclear power plant described herein shows promise of being compact, efficient, and easily maintained. The thermal efficiency approaches that of the Carnot cycle. The reactor plant is compact and cheap by virtue of the use of an unpressurized reactor with high heat transfer capabilities.

The power machinery is an 8 cylinder 2500 hp engine operating on the Stirling cycle. Modern design versions of engines operating on this cycle have shown great promise of exceeding Diesel and Otto engines in efficiency, reliability, quietness of operation and specific output. The inherent design of the Stirling engine requires no valves, no timing gears, no fuel injection; there is no exhaust or intake, as the engine operates with a closed cycle and a single permanent charge of working fluid. The reactor coolant fluid will not contaminate the engine, and will not affect the lubrication.

The components of this plant, in short, are ideally suitable for use with each other in marine and

mobile propulsion applications, and for use in remote or underground sites.

A brief description of the entire plant is given, followed by an explanation of the machinery and power cycle.

For the generation of power from nuclear energy, liquid metals offer many attractive advantages for the high temperature extraction of heat from power reactors. However, the advantages resulting from good neutron economy, high heat transfer rates, and low system pressures are often offset by chemical instability and corrosive action on the materials of the cooling system, and (possibly) high primary circuit activity.

The general requirements for the selection of liquid metal coolants are best served by lithium, sodium, potassium, mercury, lead, and bismuth, and such of their alloys as exhibit usefully low melting points. Of these possible metallic coolants, lithium exhibits the most desirable properties of the entire group. Its specific heat is appreciably higher than any other liquid metal; only one half to one third the coolant volume of other metals is required by lithium with a consequent reduction in volume and weight of the coolant circuit. Its electrical and hydraulic properties are apparently suitable for good performance with either electromagnetic or rotating pumps. Corrosion data unfortunately, is lacking, but it is reasonable to assume that purified lithium will be no harder to handle than, for instance, sodium.

The most significant objection to natural lithium as a reactor coolant is based on its high thermal neutron absorption. Naturally occurring lithium, however, consists of two isotopes: 92.5 percent of Li^7 and 7.5 percent of Li^6. The high thermal neutron absorption is due entirely to the latter isotope. Li^7, the majority isotope in natural lithium, has an attractively low neutron capture cross section, is suitable for use as a moderator, and has no significant induced activity on irradiation. The isotope at present (with an estimated cost of $500/lb) is too expensive to consider in any concept but one which is specifically oriented to its economical use. There is no doubt that, even as the price of natural lithium has been reduced, the isotope Li^7 may be produced at a price to justify its use in this reactor.

In a marine propulsion plant, where both space and weight are at a premium, the low primary circuit activity and the 0.85 second half life of the Li^7 coolant permits its use directly into the heater section of the thermal engine with which it is proposed to be used. Such an arrangement would require only a lightly shielded primary circuit, and would save a considerable amount of weight and complication both in shielding and in the elimination of secondary pumps and heat exchangers.

The proposed reactor is contained in a vessel pressurized only enough to permit the use of an inert blanket gas, to exclude air. Such a vessel should be extremely cheap to construct because heavy construction and leakproof packings are almost unnecessary. The vessel can be readily opened for servicing, since heavy bolting is not required. Packings, where used, will have a leak-off connection so that leakage of the pressurizing gas may be collected and purified. The leak-off gas may also serve to cool the packings.

The proposed core will be approximately 20″ in diameter, and 40″ high, and will contain about 3500 lbs of slightly enriched uranium. The fuel will be an arrangement of 280 ceramic or metal clad cylindrical elements, permanently held in a removable steel basket. The control rods will be supported by the cover of the pressure vessel, and all may be entirely removed as an assembly integral with the pressure vessel cover. Scram may be accomplished by rod insertion, supplemented by discharge of moderator from the pressure vessel into a receiving tank.

The Li^7 serves as both moderator and coolant, thus achieving an admirable simplicity of design and economy of cost. The reactor has the simplicity of a boiling water design without the problems incident to high pressure and the limitations due to boiling.

Extreme simplicity of design and construction is inherent in this design. The lithium melts at 179°C, and boils at 1300°C so that temperature limitations are imposed by metallurgical rather than coolant considerations.

The fuel elements will not be rearranged to compensate for uneven burnup; the moderator level will be varied to provide burnup compensation. When the core is considered exhausted, the cover of the reactor vessel will be removed, together with

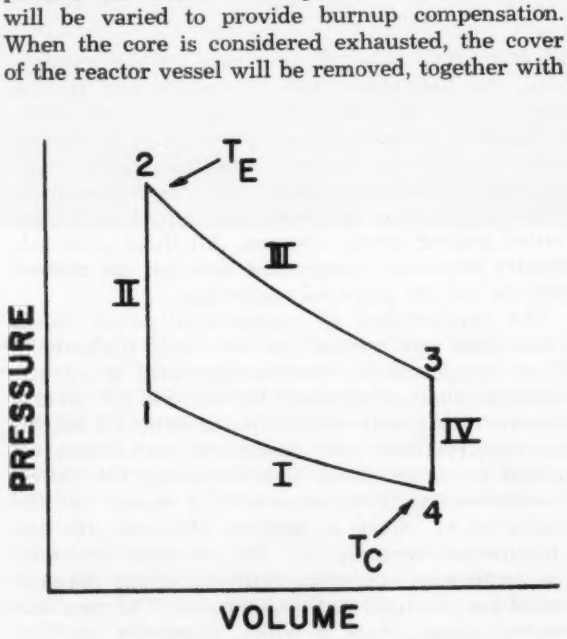


Figure 1. Ideal Cycle Diagram.

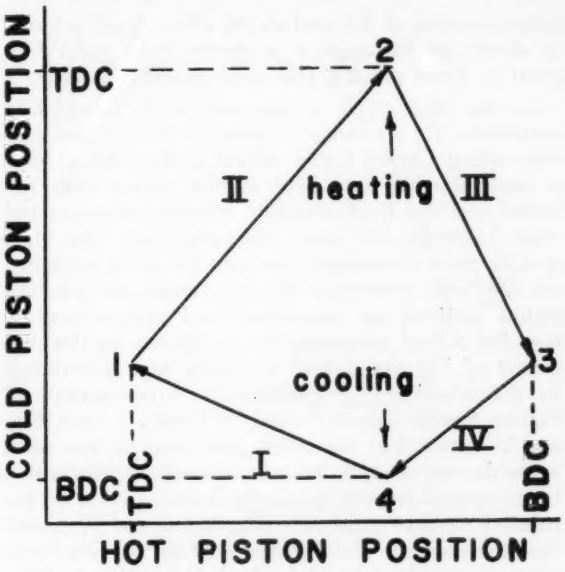


Figure 2. Relative Piston Position.

the control rods, and a shielded grapple will remove the entire load, replacing it with a fresh loading. The entire reloading operation will require only minutes, and may be accomplished even while the elements are hot. The exhausted core is then stored for decay, and subsequently shipped to a processing center for reprocessing. The cost of the structure to support the core is a minor consideration compared to the capital cost savings which may be achieved by this simplicity of design.

If unclad ceramic fuel elements are used, fission gases will collect in the reactor vessel, mixing with the pressurizing gas. When it is necessary to blowdown some of the pressurizing gas, the blowdown is diverted through a holdup tank, filters, and traps. The packing leak-offs will be used as a continuous bleed for side-stream purification. Although the presence of fission gases in the reactor vessel may not be objectionable, the possibility of their reaction with Li may make such a continuous bleed off purification system desirable. The possible contamination of Li^7 due to the diffusion of fission gases must also be considered. The purification system for the lithium should offer no difficulty, as the activation and half life of the radioactive products are extremely small. However, the problem of lithium purification will require study, because of the lack of experience concerning the reactions between molten lithium and fission gases or fuel element particulates.

The "throw away" core is a unique concept designed to cope with the difficulties of fueling in the field, and with the deterioration which may be expected due to the use of a possibly difficult coolant. Since the core is small, the method is feasible.

The reactor vessel will be less than 5′ high, and less than 2′ in diameter. It is estimated that the weight of the entire vessel will be in the neighborhood of 10,000 lbs. The small size of the vessel allows the economical use of a high density primary shield, with resultant space and weight savings. The primary coolant system will require about 140 lbs of Li^7, having an estimated cost of $70,000.

STIRLING ENGINE

The propulsion engine consists of eight to sixteen cylinders, arranged in "V" form with an angle of 90° between the cylinder banks. Figure 4 shows the arrangement of a typical pair of cylinders. The operation of the Stirling engine is completely governed by the relative motion of the two pistons which are attached to a common crank throw, and which have a rotational phase difference of 90° between them. The basic functions of the pistons may be seen from an examination of Figure 3. It is evident that all of the thermodynamic fluid is contained in the total volume represented by the volumes of the 3 spaces which may be designated as follows: (1) the variable volume of the hot space in the left hand cylinder above the piston; (2) the internal volume of the heater, regenerator, cooler and piping; (3) the variable volume of the cold space in the right hand cylinder above the piston. The total volume of the working fluid is therefore determined by the relative positions of the two pistons.

The only requirement for the phase relationship

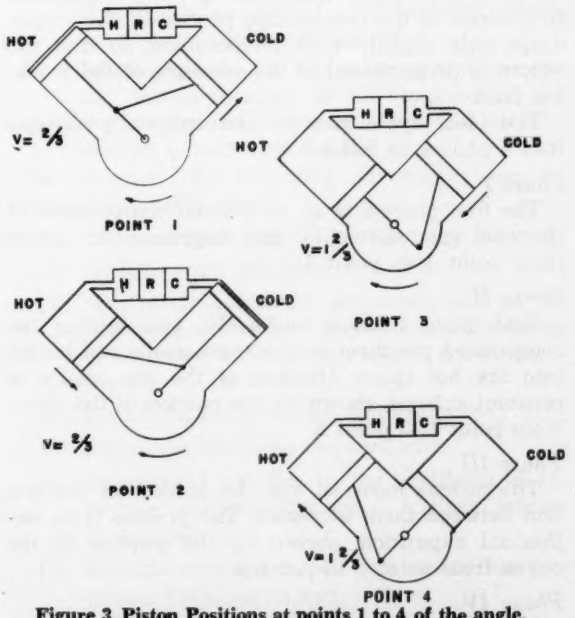


Figure 3. Piston Positions at points 1 to 4 of the angle.
V—Relative Volume of Thermodynamic Fluid.
HRS—Heater, Regenerator, Cooler.

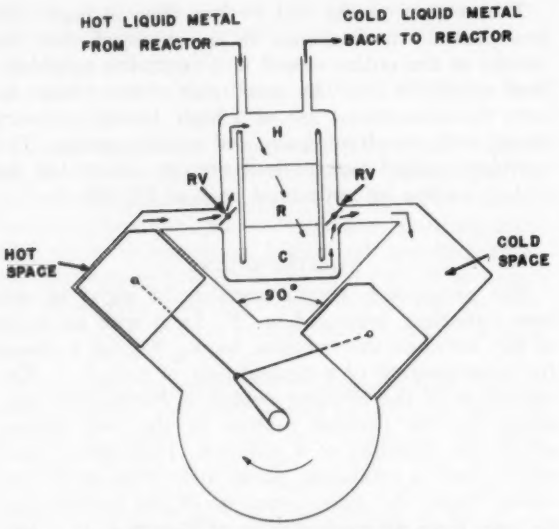


Figure 4. RV-Reversing Valves. H-Heating Section. R-Regenerator. C-Cooling System.

of the two pistons is that the "hot" piston should lead the "cold" piston by 90°.

The ideal Stirling cycle is most conveniently described by the sequence of piston positions shown in Figure 2 and 3; the corresponding ideal PV diagram is shown in Figure 1. By proper design of the heat exchangers, and phasing of the pistons, the working fluid can be displaced through the heat exchangers in such a manner that the processes of the ideal cycle are approximated.

The cycle is easily described by the PV diagram. In contrast to the evaporation processes, the output drops only slightly with temperature, so that the output is proportional to the pressure of the working fluid.

The ideal cycle may be conventionally divided into 4 phases as follows:

space. Cooling of the gas occurs at constant volume, as shown by the portion of curve from point 3 to point 4. From point 4 the cycle repeats itself.

As the ideal cycle is assumed to be completely reversible, its efficiency is equal to that of the corresponding Carnot cycle, which is the highest that is attainable for any heat engine. Since both the initial and the final constant volume processes operate between the same isotherms, and the ideal specific heat is constant, the heat involved is identical for both processes. In the actual process, the piston motions are sinusoidal and progressive, so that the actual processes are as shown by the diagrams of Figures 5 and 6, which are determined by the actual engine parameters. A comparison of Figure 5 with Figure 1, and of Figure 6 with Figure 2 shows that the four processes of the ideal cycle do not seem to be even closely approximated by an actual engine; however, a comparison of the relative motion diagrams (Figures 2 and 6) shows that the position of the piston and bottom dead centers are clearly defined for both the actual and the ideal engines. The ideal and actual cycles may thus be compared by their respective cycle diagrams and piston relative motion diagrams.

Between the temperature limits of 1250°F and 200°F, represented by T_E and T_C on Figure 1, the ideal cycle has an efficiency of 70 percent. The actual engine shaft thermal efficiency which may be anticipated with modern design including all friction and process losses, is in the neighborhood of 60 percent of the ideal. On the basis of the ideal analysis alone, it is obvious that the regenerator is an essential contributor to the attainment of this practical thermal utilization. Regenerator theory has been extensively explored in recent years, both theoretically and empirically, and actual efficiencies in excess of 98 percent are possible.

The power output of the engine is regulated by changing the pressure of the thermodynamic fluid within the working volume. The reactor is con-

ably higher load but with a marked change in the friction-torque curve in the area corresponding to the failure in the first case. The first extreme-pressure oil did not fail at the limiting load of the machine, but showed distinct changes in friction characteristic in areas corresponding to the two plain-oil failures. The second extreme-pressure oil showed lower friction torques than the plain oil or the first extreme-pressure oil, but failed at a load similar to that of the low plain-oil failure.

Figure 1(c) shows results for a condition of high-speed and low-slide/roll ratio. The friction-torque-load relationship is practically linear and indistinguishable as between the plain and the extreme-pressure oils, although with the plain oil scuffing occurred before the limit of the machine was reached. Figure 1(d) shows a similar relationship from a low-speed low-slide/roll ratio condition, but it should be noted that the friction torques are higher than those in Figure 1(c) for corresponding loads.

These results illustrate several typical characteristics. With the plain oil under the conditions in these tests the friction-torque-load curve is usually reasonably linear up to final failure, as, for example, those in Figures 1(a) and 1(c), and generally with a low coefficient of friction a high failure load is achieved and *vice versa*, the actual friction torque at failure being very approximately constant. On occasion, however, as illustrated in Figure 1(b), two distinct levels of failure load are seen, with an indication of change in the friction curve leading to the higher failure load in the area of the lower failure load. These results suggest that with a plain oil the failure generally has a primary cause, probably

many cases, however, the friction torque at failure is similar to that of the plain oil. In other cases, however, again particularly at low speeds, although the friction-torque level is relatively low, failure occurs at a load similar to or lower than that achieved by the plain oil.

FUTURE REQUIREMENTS

Present merchant-ship gear designs in general combine alloy-steel pinions with carbon-steel wheels, and the limit of this type of gear has probably almost been reached with gears having K factors between 100 and 110 now at sea. The trend towards larger tankers, though not in itself necessarily increasing gear nominal loading, may increase maneuvering loads, and the cost of a prolonged running-in period increases. The use of extreme-pressure oils for the initial charge in such machinery appears established therefore, since it allows rapid bedding of the gears by protecting high spots against scuffing long enough for them to be demolished by wear or deformation.

Increase on this level of loading appears bound to occur, to achieve smaller and lighter gears, and this requires enhancement of the resistance to surface fatigue and bending fatigue of the gear materials, particularly that of the wheels. It is likely that the generally acceptable limit of such properties in carbon steels has been reached, so that further improvement must be gained by using alloy steels for wheel rims or finally by surface-hardening processes. Troubles have been experienced with alloy steel combinations, which, so far as scuffing is concerned, in general, have been overcome by the use of extreme-pressure oils. Apart from the apparent lack of compatibility of some alloy steel combinations when a plain oil is used, relatively high yield

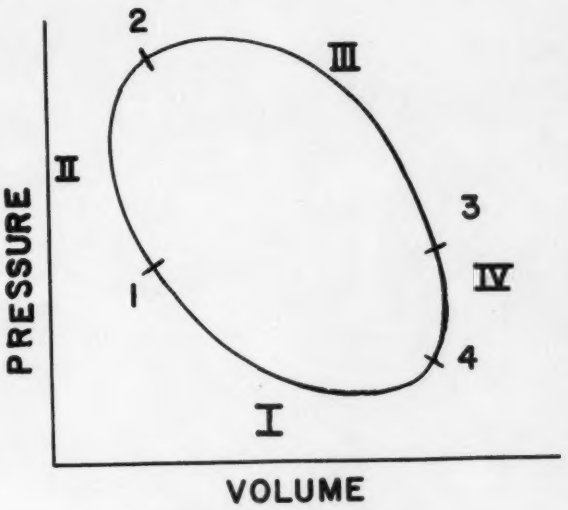


Figure 5. Actual Cycle Diagram.

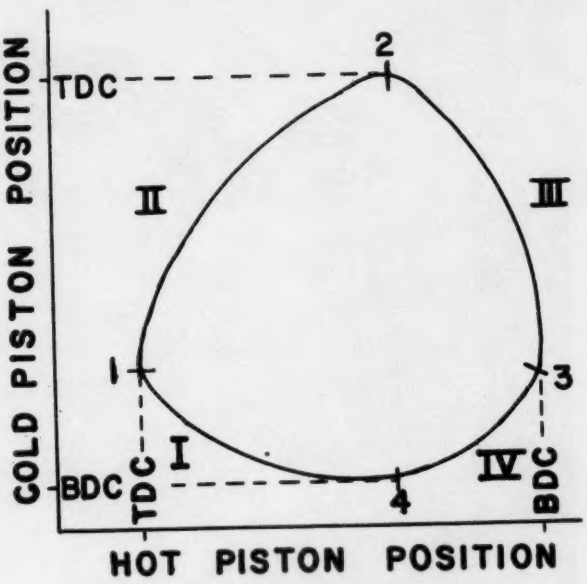


Figure 6. Relative Piston Position.

It may be an exceptionally good heat transfer medium. Its unique possibilities as a thermodynamic fluid stem from the possible advantages arising from its dissassociation and the consequent increase in effective specific heat and thermal conductivity. Lowering the temperature of the gas will yield not only the heat given off as if the composition of the gas were "frozen", but since the gas is more highly associated at lower temperatures, it will also give off the chemical heat due to the association of some of the monomer molecules that result from lowering the temperature. The effect on the efficiency and size of the regenerator should be significant.

An additional advantage of this power plant is the convenient possibility of heating the liquid lithium with an external oil fired boiler, thus permitting complete shutdown of the reactor plant for in-port operation.

Inasmuch as the engine requires no valves, gears,

actor. These problems have been exhaustively explored and are believed amenable to present day technology.

(b) Mechanical, in connection with the design of the engine. Considerable work has been done on this type of thermal power producer, and the problem is essentially one of determining the parameters and designing the engine. Based upon the success of the work already accomplished, satisfactory design may be reasonably anticipated.

(c) In connection with the value of the concept, and the application of the engineering for the "throw away" reactor. These are all considered a matter of detail.

In summary, the following advantages may be realized with this design:

The solar energy converters used in NASA's lunar study will provide the power for a television camera system and other instruments that will transmit data back to earth during the flight to the moon.

FARTHER FATHOMS—Submersibles can be propelled to "depths previously considered impossible," up to 7,000 feet, with a new underwater propulsion system developed by Avien, Inc., President Leo A. Weiss of the Woodside, N. Y., firm reports. The system features use of an exhaust gas compressor capable of operating under pressures of up to 3200 psi, solving the problem of reduced engine performance due to back pressure, Weiss says. A second major factor, he explains, is a fuel pump that can operate with corrosive fuels or oxidants, the types of combinations that have the attraction of high energy potential with greatly reduced vehicle weight and volume.

—Research/Development, September 1960

"CAT'S EYES" FOR FROGMEN—Particularly valuable under zero visibility in dark or murky water, says Stromberg-Carlson, division of General Dynamics Corp., is economical new hand-held sonar equipment it has developed jointly with U. S. Navy Electronics Laboratory. Designated AN/PQS-1, the device is slightly larger than a basketball, one cubic foot in volume; has aluminum casing with hand grips. Earphones provide the underwater operator with audio information on objects detected by the searching sonar beam. Standard batteries power the transistorized portable object locator—a feature expected to save more than 90 per cent in battery replacement costs. Battery life of up to 40 hours is anticipated, due to low power requirements of transistorized circuitry. Ten prototypes will be delivered this year under Bureau of Ships contract.

—Research/Development, August 1960

The challenge of silence

The wide and deep sea is a near-perfect hiding place . . . and an infinitely mobile missile launching pad. This makes anti-submarine warfare a high-priority defense problem.

Not just the sea, but the surface and the air as well, comprise the theatre of ASW. And in all these areas, Sperry is making advanced contributions: submarine sonar detection gear . . . submarine fire control systems . . . submarine depth and maneuvering controls . . . countermeasures and counter-countermeasures . . . sophisticated navigational computers for helicopters, capable of programming a systematically precise sub search . . . automatic flight controls for the helicopter to permit it to do its job despite the vagaries of weather or mission complexity . . . for surface ships, precision torpedo fire control and hydrofoil stabilization and control systems.

Most of today's ASW programs utilize sound radiation techniques. But being explored are myriad "unsound" techniques of sea-hunting, vast new frontier for scientist and engineer . . . investigations in the electro-magnetic spectrum . . . development of advanced transducers, data processors, and means of displaying data that is gathered.

These anti-submarine warfare programs, ranging through the three dimensions of our environment, typify the *integrated* capability of the Sperry organization today. General offices, Great Neck, N. Y.

SEA • SURFACE • AIR • SPACE

SPERRY

PAUL N. GARAY

A NEW CONCEPT FOR A NUCLEAR POWER MARINE PROPULSION PLANT

THE AUTHOR

is presently with the Gas Cooled Power Group of Kaiser Engineers, Oakland, Calif. For the past several years he has been associated with the design of nuclear power plants.

He received his engineering degree in 1941 from Northwestern University. During World War II, and the Korean War, he was an Engineering Duty officer with the U.S. Navy.

His numerous articles concerning the operation and design of power and nuclear facilities have been published in various technical journals.

RECENT STUDIES which have been made in connection with the development of mobile and marine power plants indicate a wide field of application for a compact, effective power plant using a nuclear fission heat source. Suggested designs to date have included boiling water plants, steam cooled reactors, pressurized water systems, and direct cycle gas cooled reactor power systems. All these proposals require extensive compromise between the desired criteria and the practical application.

The requirements of conventional power plants for mobile and marine use are well understood. These requirements, when incorporated in nuclear concepts, must of necessity be modified for several reasons: (1) containment requirements; (2) shielding requirements; (3) specialized techniques required for maintenance and refueling; (4) limitations governing the disposal of solid wastes, and the discharge of liquid or gaseous effluents; (5) environmental hazards; (6) the economic necessity for continuous operation, with minimum time allowed for overhaul and maintenance. The resultant nuclear power plant is bulky, expensive, and demands the attentions of highly specialized personnel. Altogether, it is a special purpose plant, the use of which is justified only under very specific conditions.

The nuclear power plant described herein shows promise of being compact, efficient, and easily maintained. The thermal efficiency approaches that of the Carnot cycle. The reactor plant is compact and cheap by virtue of the use of an unpressurized reactor with high heat transfer capabilities.

The power machinery is an 8 cylinder 2500 hp engine operating on the Stirling cycle. Modern design versions of engines operating on this cycle have shown great promise of exceeding Diesel and Otto engines in efficiency, reliability, quietness of operation and specific output. The inherent design of the Stirling engine requires no valves, no timing gears, no fuel injection; there is no exhaust or intake, as the engine operates with a closed cycle and a single permanent charge of working fluid. The reactor coolant fluid will not contaminate the engine, and will not affect the lubrication.

The components of this plant, in short, are ideally suitable for use with each other in marine and

mobile propulsion applications, and for use in remote or underground sites.

A brief description of the entire plant is given, followed by an explanation of the machinery and power cycle.

For the generation of power from nuclear energy, liquid metals offer many attractive advantages for the high temperature extraction of heat from power reactors. However, the advantages resulting from good neutron economy, high heat transfer rates, and low system pressures are often offset by chemical instability and corrosive action on the materials of the cooling system, and (possibly) high primary circuit activity.

The general requirements for the selection of liquid metal coolants are best served by lithium, sodium, potassium, mercury, lead, and bismuth, and such of their alloys as exhibit usefully low melting points. Of these possible metallic coolants, lithium exhibits the most desirable properties of the entire group. Its specific heat is appreciably higher than any other liquid metal; only one half to one third the coolant volume of other metals is required by lithium with a consequent reduction in volume and weight of the coolant circuit. Its electrical and hydraulic properties are apparently suitable for good performance with either electromagnetic or rotating pumps. Corrosion data unfortunately, is lacking, but it is reasonable to assume that purified lithium will be no harder to handle than, for instance, sodium.

The most significant objection to natural lithium as a reactor coolant is based on its high thermal neutron absorption. Naturally occurring lithium, however, consists of two isotopes: 92.5 percent of Li^7 and 7.5 percent of Li^6. The high thermal neutron absorption is due entirely to the latter isotope. Li^7, the majority isotope in natural lithium, has an attractively low neutron capture cross section, is suitable for use as a moderator, and has no significant induced activity on irradiation. The isotope at present (with an estimated cost of $500/lb) is too expensive to consider in any concept but one which is specifically oriented to its economical use. There is no doubt that, even as the price of natural lithium has been reduced, the isotope Li^7 may be produced at a price to justify its use in this reactor.

In a marine propulsion plant, where both space and weight are at a premium, the low primary circuit activity and the 0.85 second half life of the Li^7 coolant permits its use directly into the heater section of the thermal engine with which it is proposed to be used. Such an arrangement would require only a lightly shielded primary circuit, and would save a considerable amount of weight and complication both in shielding and in the elimination of secondary pumps and heat exchangers.

The proposed reactor is contained in a vessel pressurized only enough to permit the use of an inert blanket gas, to exclude air. Such a vessel should be extremely cheap to construct because heavy construction and leakproof packings are almost unnecessary. The vessel can be readily opened for servicing, since heavy bolting is not required. Packings, where used, will have a leak-off connection so that leakage of the pressurizing gas may be collected and purified. The leak-off gas may also serve to cool the packings.

The proposed core will be approximately 20″ in diameter, and 40″ high, and will contain about 3500 lbs of slightly enriched uranium. The fuel will be an arrangement of 280 ceramic or metal clad cylindrical elements, permanently held in a removable steel basket. The control rods will be supported by the cover of the pressure vessel, and all may be entirely removed as an assembly integral with the pressure vessel cover. Scram may be accomplished by rod insertion, supplemented by discharge of moderator from the pressure vessel into a receiving tank.

The Li^7 serves as both moderator and coolant, thus achieving an admirable simplicity of design and economy of cost. The reactor has the simplicity of a boiling water design without the problems incident to high pressure and the limitations due to boiling.

Extreme simplicity of design and construction is inherent in this design. The lithium melts at 179°C, and boils at 1300°C so that temperature limitations are imposed by metallurgical rather than coolant considerations.

The fuel elements will not be rearranged to compensate for uneven burnup; the moderator level will be varied to provide burnup compensation. When the core is considered exhausted, the cover of the reactor vessel will be removed, together with

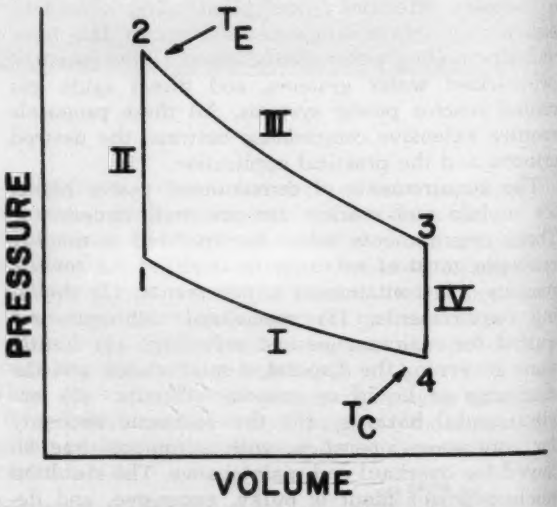


Figure 1. Ideal Cycle Diagram.

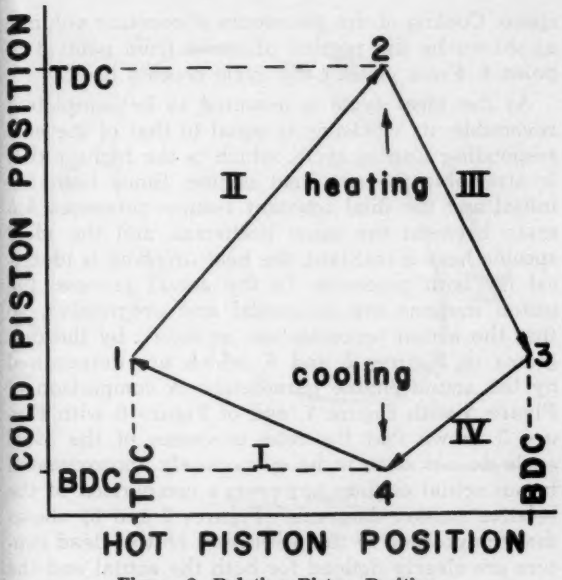


Figure 2. Relative Piston Position.

the control rods, and a shielded grapple will remove the entire load, replacing it with a fresh loading. The entire reloading operation will require only minutes, and may be accomplished even while the elements are hot. The exhausted core is then stored for decay, and subsequently shipped to a processing center for reprocessing. The cost of the structure to support the core is a minor consideration compared to the capital cost savings which may be achieved by this simplicity of design.

If unclad ceramic fuel elements are used, fission gases will collect in the reactor vessel, mixing with the pressurizing gas. When it is necessary to blowdown some of the pressurizing gas, the blowdown is diverted through a holdup tank, filters, and traps. The packing leak-offs will be used as a continuous bleed for side-stream purification. Although the presence of fission gases in the reactor vessel may not be objectionable, the possibility of their reaction with Li may make such a continuous bleed off purification system desirable. The possible contamination of Li^7 due to the diffusion of fission gases must also be considered. The purification system for the lithium should offer no difficulty, as the activation and half life of the radioactive products are extremely small. However, the problem of lithium purification will require study, because of the lack of experience concerning the reactions between molten lithium and fission gases or fuel element particulates.

The "throw away" core is a unique concept designed to cope with the difficulties of fueling in the field, and with the deterioration which may be expected due to the use of a possibly difficult coolant. Since the core is small, the method is feasible.

The reactor vessel will be less than 5′ high, and less than 2′ in diameter. It is estimated that the weight of the entire vessel will be in the neighborhood of 10,000 lbs. The small size of the vessel allows the economical use of a high density primary shield, with resultant space and weight savings. The primary coolant system will require about 140 lbs of Li^7, having an estimated cost of $70,000.

STIRLING ENGINE

The propulsion engine consists of eight to sixteen cylinders, arranged in "V" form with an angle of 90° between the cylinder banks. Figure 4 shows the arrangement of a typical pair of cylinders. The operation of the Stirling engine is completely governed by the relative motion of the two pistons which are attached to a common crank throw, and which have a rotational phase difference of 90° between them. The basic functions of the pistons may be seen from an examination of Figure 3. It is evident that all of the thermodynamic fluid is contained in the total volume represented by the volumes of the 3 spaces which may be designated as follows: (1) the variable volume of the hot space in the left hand cylinder above the piston; (2) the internal volume of the heater, regenerator, cooler and piping; (3) the variable volume of the cold space in the right hand cylinder above the piston. The total volume of the working fluid is therefore determined by the relative positions of the two pistons.

The only requirement for the phase relationship

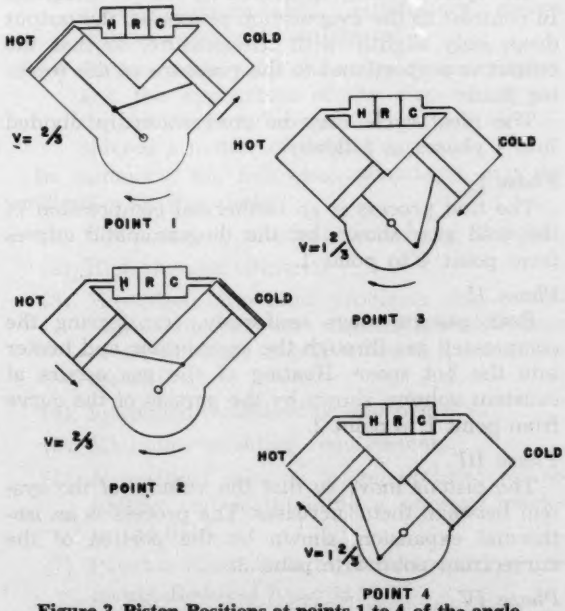


Figure 3. Piston Positions at points 1 to 4 of the angle.
V—Relative Volume of Thermodynamic Fluid.
HRS—Heater, Regenerator, Cooler.

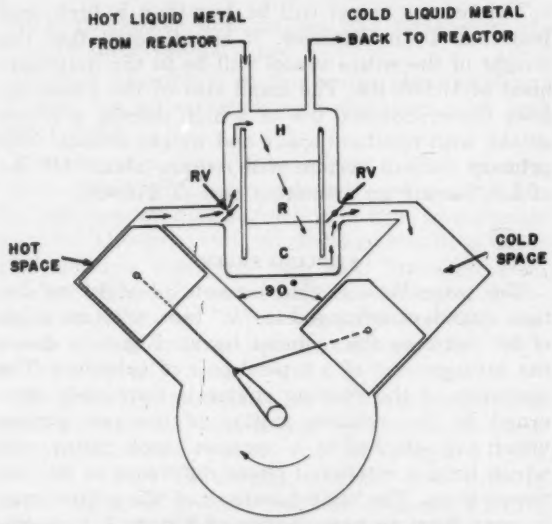


Figure 4. RV-Reversing Valves. H-Heating Section. R-Regenerator. C-Cooling System.

of the two pistons is that the "hot" piston should lead the "cold" piston by 90°.

The ideal Stirling cycle is most conveniently described by the sequence of piston positions shown in Figure 2 and 3; the corresponding ideal PV diagram is shown in Figure 1. By proper design of the heat exchangers, and phasing of the pistons, the working fluid can be displaced through the heat exchangers in such a manner that the processes of the ideal cycle are approximated.

The cycle is easily described by the PV diagram. In contrast to the evaporation processes, the output drops only slightly with temperature, so that the output is proportional to the pressure of the working fluid.

The ideal cycle may be conventionally divided into 4 phases as follows:

Phase I

The first process is an isothermal compression of the cold gas; shown by the diagrammatic curves from point 4 to point 1.

Phase II

Both pistons move uniformly, transferring the compressed gas through the regenerator and heater into the hot space. Heating of the gas occurs at constant volume, shown by the portion of the curve from point 1 to point 2.

Phase III

The pistons move so that the volume of the system between them increases. The process is an isothermal expansion, shown by the portion of the curve from point 2 to point 3.

Phase IV

Uniform motion of the pistons transfers the gas through the regenerator and cooler into the cold space. Cooling of the gas occurs at constant volume, as shown by the portion of curve from point 3 to point 4. From point 4 the cycle repeats itself.

As the ideal cycle is assumed to be completely reversible, its efficiency is equal to that of the corresponding Carnot cycle, which is the highest that is attainable for any heat engine. Since both the initial and the final constant volume processes operate between the same isotherms, and the ideal specific heat is constant, the heat involved is identical for both processes. In the actual process, the piston motions are sinusoidal and progressive, so that the actual processes are as shown by the diagrams of Figures 5 and 6, which are determined by the actual engine parameters. A comparison of Figure 5 with Figure 1, and of Figure 6 with Figure 2 shows that the four processes of the ideal cycle do not seem to be even closely approximated by an actual engine; however, a comparison of the relative motion diagrams (Figures 2 and 6) shows that the position of the piston and bottom dead centers are clearly defined for both the actual and the ideal engines. The ideal and actual cycles may thus be compared by their respective cycle diagrams and piston relative motion diagrams.

Between the temperature limits of 1250°F and 200°F, represented by T_E and T_C on Figure 1, the ideal cycle has an efficiency of 70 percent. The actual engine shaft thermal efficiency which may be anticipated with modern design including all friction and process losses, is in the neighborhood of 60 percent of the ideal. On the basis of the ideal analysis alone, it is obvious that the regenerator is an essential contributor to the attainment of this practical thermal utilization. Regenerator theory has been extensively explored in recent years, both theoretically and empirically, and actual efficiencies in excess of 98 percent are possible.

The power output of the engine is regulated by changing the pressure of the thermodynamic fluid within the working volume. The reactor is controlled to produce a constant temperature regardless of the engine load level, so that the design temperature conditions of the reactor are always closely maintained. The direction of rotation of the engine is very simply reversed by reversing the direction of gas flow through the heat exchanger. The reversal is accomplished by the interconnected valves RV shown in Figure 4.

The thermodynamic properties of the working fluid are very important. The excellent properties of hydrogen make it a favorite choice for this application; helium, which is a somewhat less reactive gas, results in an efficiency decrease of about 12 percent. An excellent possibility for a working fluid is aluminum chloride in the gaseous form. It is particularly attractive for this application since it exists as the monomer $AlCl_3$ at high temperature, and as the dimer Al_2Cl_6 at low temperatures.

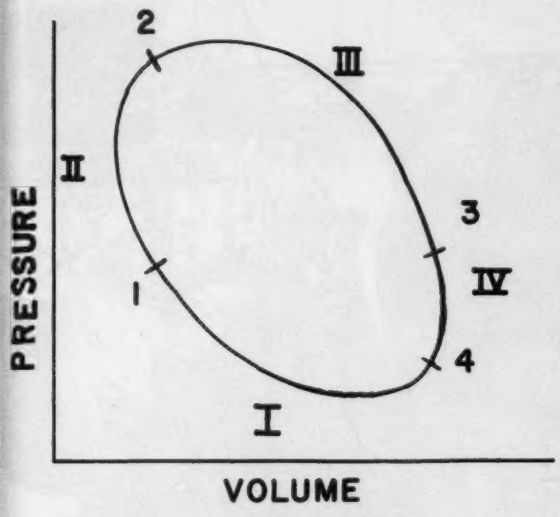


Figure 5. Actual Cycle Diagram.

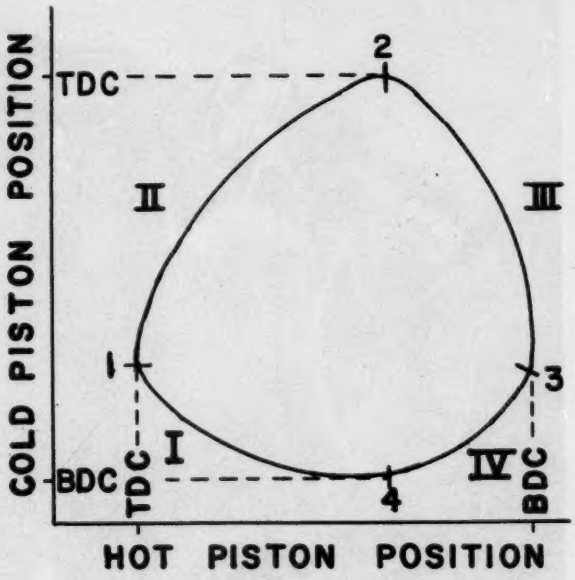


Figure 6. Relative Piston Position.

It may be an exceptionally good heat transfer medium. Its unique possibilities as a thermodynamic fluid stem from the possible advantages arising from its dissassociation and the consequent increase in effective specific heat and thermal conductivity. Lowering the temperature of the gas will yield not only the heat given off as if the composition of the gas were "frozen", but since the gas is more highly associated at lower temperatures, it will also give off the chemical heat due to the association of some of the monomer molecules that result from lowering the temperature. The effect on the efficiency and size of the regenerator should be significant.

An additional advantage of this power plant is the convenient possibility of heating the liquid lithium with an external oil fired boiler, thus permitting complete shutdown of the reactor plant for in-port operation.

Inasmuch as the engine requires no valves, gears, or timing mechanisms, reliability should be greater than that of a corresponding Diesel unit.

A recent ORNL study has proposed the use of a reciprocating piston engine in connection with a gas cooled reactor. The concept, while interesting, cannot be compared to the Li^7 cooled reactor used in conjunction with a Stirling cycle hot gas engine, as herein described. The small size, lack of complex reactor mechanisms, high heat transfer rates, high engine efficiency, low pumping power, and minimum of radioactive contamination are all virtues of this reactor which cannot be approached in a gas cooled design.

The anticipated problems in connection with this design may be categorized as follows:

(a) Nuclear, in connection with the use of liquid metal coolants, and the design of the reactor. These problems have been exhaustively explored and are believed amenable to present day technology.

(b) Mechanical, in connection with the design of the engine. Considerable work has been done on this type of thermal power producer, and the problem is essentially one of determining the parameters and designing the engine. Based upon the success of the work already accomplished, satisfactory design may be reasonably anticipated.

(c) In connection with the value of the concept, and the application of the engineering for the "throw away" reactor. These are all considered a matter of detail.

In summary, the following advantages may be realized with this design:

(1) Compactness, simplicity, minimum weight.

(2) High thermal efficiency.

(3) Minimized attendant problems due to requirements of waste disposal and discharge of activated air and/or water to the environment.

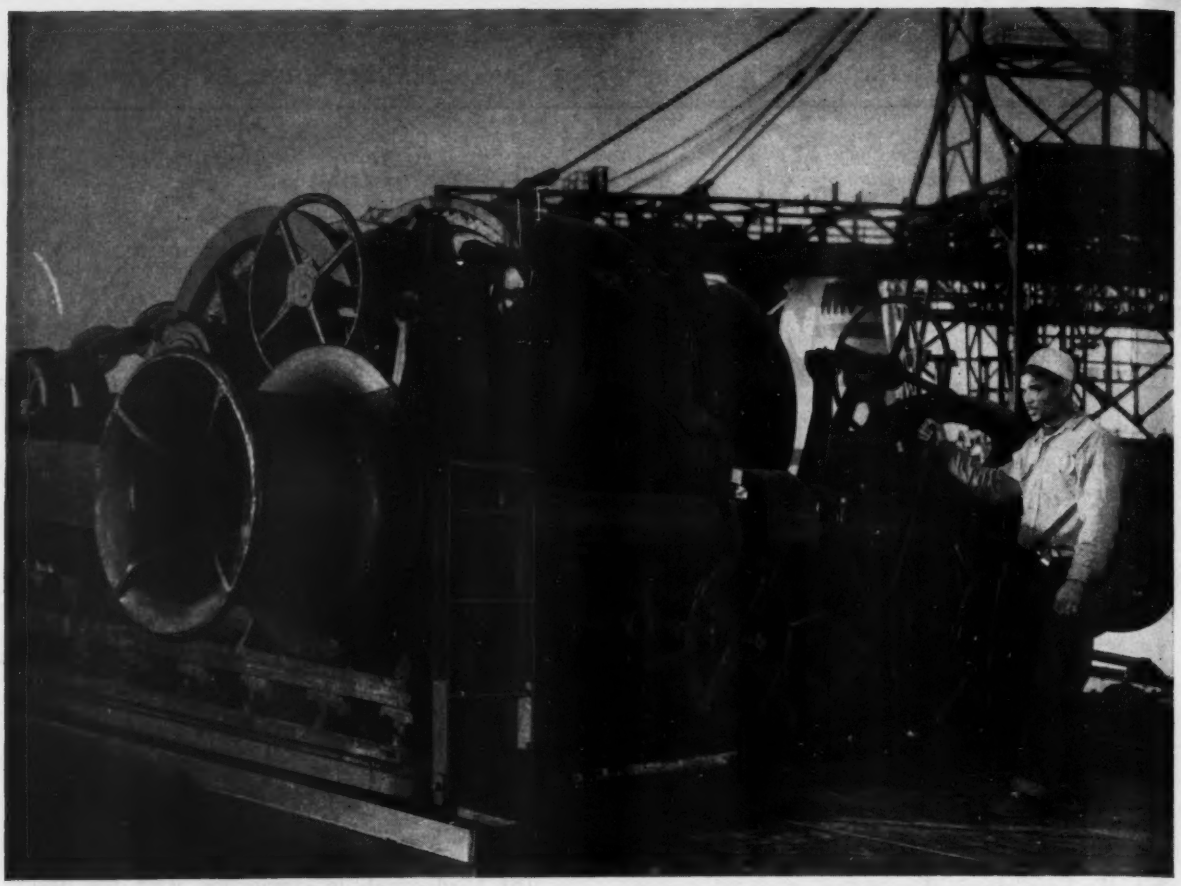
(4) Simplified maintenance and operation.

(5) Minimum shielding requirements.

(6) A practical solution to the problems of refueling and maintaining a nuclear reactor in the field.

(7) Possible elimination of containment requirements. Reduced hazards.

(8) Adaptability to multiple uses. Minimum location and site problems.



"K" Monel shafts in deck machinery can handle the toughest jobs

Shafting in auxiliary machinery aboard ship must be strong and tough, and corrosion-resisting, to keep vital equipment operating without interruption for long periods, both at sea and in port.

"K" Monel* age-hardenable nickel-copper alloy is one shafting material with *all* of these properties!

It possesses the excellent corrosion resistance of Seagoin'* Monel alloy together with the added advantages of greater strength and hardness, because "K" Monel is age-hardenable (capable of having its properties increased by heat treatment).

More specifically, here's what "K" Monel offers:
High Strength, stiffness, and torsional properties to transmit power with minimum vibration. "K" Monel has remarkable resistance to fatigue — to the repeated stresses a shaft has to undergo.
Hardness to resist abrasion and scoring. This means more protection against shaft wear — longer bearing life.
Corrosion resistance. This nickel-copper alloy resists corrosion, pitting, and corrosion fatigue in sea water as well as fresh and polluted waters.
Galvanic neutrality, when coupled with bronze pump bodies and bearings.
Non-magnetic. "K" Monel alloy is non-magnetic under ordinary conditions, and remains so down to −150°F.

Time and time again, this seaworthy alloy has proved itself, below decks and topside...in deck machinery, sleeves, valves, wearing rings, springs, and in pumps of all kinds. These are only a few uses for this versatile alloy.

If you would like to know more about "K" Monel alloy, write for our 28-page reference manual "Engineering Properties of "K" Monel and "KR" Monel". We'll also be glad to answer your questions about other high nickel alloys. Just write to:

*Inco trademark

HUNTINGTON ALLOY PRODUCTS DIVISION
The International Nickel Company, Inc.
Huntington 17, West Virginia

"K" MONEL

"AMERICAN SOCIETY OF MECHANICAL ENGINEERS"

REPORT ON 9000 HOUR OPERATION OF MARINE PROPULSION GAS TURBINE IN THE JOHN SERGEANT

ACKNOWLEDGMENT

This is a reprint of American Society of Mechanical Engineers paper 60-GTP-5 presented at the Gas Turbine Power and Hydraulic Conference in March 1960. The paper was written by H. D. McLean of General Electric Company, C. C. Tangerini of Maritime Administration and W. H. VanCott, Chief Engineer of JOHN SERGEANT.

PURPOSE OF PROJECT

SELECTION OF THE regenerative, open-cycle gas-turbine drive promised improvement over conventional propulsion machinery in the following areas:

a) Easier to operate. The development of the gas-turbine engine with its inherently self-contained auxiliaries and automatic control features dispenses with the large propulsion equipment associated with a steam-turbine plant; namely, the steam-generating system with its required auxiliaries of boiler feed and condensing equipment. This fact alone justified consideration of a marine gas-turbine drive with the goal of reduced manning.

b) Less maintenance. As a result of eliminating the major components mentioned, it becomes obvious that if the main elements of a gas turbine, including the combustion system, can be developed to have durability and reliability equal to a steam-turbine plant, the advantage of the gas-turbine plant is clear and less over-all maintenance than a steam plant can be expected, and of course, far less maintenance than a diesel plant.

c) Lower specific weight and volume. For a marine installation this factor permits greater freedom of machinery arrangement within a hull design as well as an increase in the cargo deadweight capacity and freight earnings. This advantage could not be effectively shown in the *Sergeant* owing to the decision to retain a maximum part of the original auxiliary equipment to reduce conversion costs.

d) Improved fuel economy. In the power range of the *Sergeant* and with the use of heat-recovery equipment such as the regenerator and waste-heat boiler, an improved fuel rate was indicated over a modern steam-turbine plant, but not over a diesel plant.

e) Lower installed cost. As gas-turbine development work progresses for land installation and in frame sizes needed for current and future marine installations, the availability of packaged gas-turbine designs is expected to compete with other commercial prime movers. The potential saving is the lowered cost in shipyard installation work due to the elimination of supporting auxiliaries normally furnished and separately installed by the shipyard.

f) Greater power flexibility and less start-up time. Power response time on the *Sergeant* was expected to prove su-

perior to a steam-turbine plant primarily due to eliminating most of the lag associated with steam generation in a steam-turbine drive. The ability of the gas turbine (as shown in the *Sergeant*) to be started and ready for maneuvering in less than 20 minute crew time increases the desirability and value of the gas-turbine drive.

g) Adaptability to full automation. While full automation is conceivable with any type of prime mover, this practice is already a fact on land gas-turbine installations. The completely automatic, self-contained gas turbine engine as now developed, has few or no engineering problems to overcome for its consideration in a completely automated marine drive.

h) Reliability. This most important feature was expected to be demonstrated by the gas-turbine unit in the *John Sergeant* and operating experience clearly proved the outstanding reliability of this type prime mover in a marine-drive.

BACKGROUND

The conversion of the *John Sergeant* resulted from original planning initiated by the Maritime Administration in 1952 to study and determine the economic potential and feasibility of using a gas-turbine prime mover for a merchant ship installation. This study was subsequently made a part of the Liberty Ship Conversion and Engine Improvement Program involving the conversion of four Liberty ships with different types of propulsion plants. Contract plans and specifications for the *Sergeant's* conversion were completed in mid-1954 with commencement of shipyard work in August 1955 and delivery of the converted ship in September 1956 after three weeks of extensive dock tests and sea trials.

Comprehensive design, installation and operating information on the *John Sergeant* has been presented in several papers [1-8]. The General Electric Company two-shaft, open-cycle gas turbine installed in the ship is shown in Figure 1.

Commercial operation of the Sergeant started in October 1956 and was concluded in September 1959.

OPERATING EXPERIENCE

Fourteen round-trip voyages were made principally to North European ports and under all conditions of seas and weather. Ship logs show a total operating time of 9270 hours on the gas turbine and a total of 128,346 nautical miles for the ship. The highest average shaft horsepower logged for a transatlantic passage was 7260 and the lowest average shaft horsepower logged during a crossing was 5201. A total of 61,258 barrels of low-vanadium type bunker C fuel and 20,631 barrels of diesel fuel have been burned in the gas turbines. It is estimated that the number of gas-turbine starts was in excess of 1000. In 9270 hours of service operation, the following repairs were accomplished:

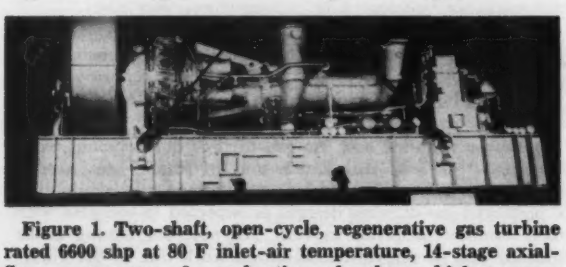


Figure 1. Two-shaft, open-cycle, regenerative gas turbine rated 6600 shp at 80 F inlet-air temperature, 14-stage axial-flow compressor, 6 combustion chambers, high-pressure turbine connected to axial-flow compressor, low-pressure turbine connected through reduction gear to main shaft. Maximum firing temperature 1450 F.

a) Atomizing air compressor failed in service as a result of dirt-scored bearings. The spare atomizing air compressor was installed, and the damaged one was rebuilt at the manufacturer's plant. After rebuilding, the unit was returned to the vessel. This repair was effected under the guarantee.

b) Replaced 6 thermocouples in turbine-exhaust monitoring system. These thermocouples were found to have the improper type of insulation for the service temperature. Replacement was made by the manufacturer under the guarantee.

c) Repaired starting-turbine self-synchronizing clutch. This clutch was damaged by a gas-turbine tripout during startup. The steam starting turbine had reached its governed speed of 4000 rpm. The high-pressure turbine and compressor were accelerating to their base speed of 5000 rpm when a tripout occurred. As the compressor set decelerated rapidly to the governed speed of the starting turbine, the clutch engaged, and the starting-turbine governor applied full cranking steam. The shock of this abnormal engagement was such that severe damage resulted to the clutch. The ship's force disassembled the clutch and installed the spare parts. To prevent a reoccurrence of this clutch damage, the starting-turbine-governor speed was reset slightly above the overspeed trip setting. This insures that during each startup the clutch will remain engaged up to 4150 rpm where the starting-turbine overspeed trip will function to shut it down. The clutch will be disengaged, and in the event of a gas-turbine tripout no damage to the clutch can occur.

d) Dirt scoring of No. 5 turbine bearing, and thrust shoes. On a routine inspection this combined journal and thrust bearing was found to be badly dirt scored. Although these bearings had not lost their original dimensions the scoring was severe and it was deemed prudent to install the spare bearings. The damaged bearings were rebabbitted by the manufacturer and returned to the vessel as spares.

It should be noted, that of the parts replaced and repaired three items are directly chargeable to dirt in the lube system, and one item to an oversight in setting up the starting sequence system.

Availability and reliability of the gas turbine have been exceptional. Actually no loss of availability or stoppage was directly chargeable to the gas turbine itself. At no time has the combustion system, axial-flow compressor, high-pressure turbine, or load turbine been responsible for a forced outage. All unscheduled outages have been caused either by accessories, or some slight malfunction of the control system.

A list of all forced outages of the gas turbine, the cause and loss of availability follows:

a) Failure of atomizing air compressor; caused by dirt-scored bearings; detention, 4.5 hours at sea.

b) Faulty turbine-exhaust temperature detector signaled excess exhaust-temperature, tripping out gas turbine; caused by cracked output air tubing; detention, 5 minutes at sea.

c) Control malfunction operated gas-turbine fuel-oil transfer valve resulting in a tripout; caused by an electrical short in the wiring to the motor-operated fuel transfer valve; detention, 2.5 hours at sea.

d) High-temperature tripout of the gas turbine while increasing power; caused by the temperature detectors being completely plugged and fouled by the fuel-oil corrosion inhibitor in ash; detention, 14 hours at sea.

Note: After this tripout (due to the temperature detectors plugging) a new type detector was furnished and installed. These new detectors cannot plug and this problem is eliminated.

Availability of the gas turbine including its controls and accessories has been 99.7 per cent.

Crew training has presented no real problem. Personnel of average ability can make the transition from a steam-turbine plant to a gas-turbine plant in about the same time the change from a steam reciprocating engine to a steam-turbine plant could be made. The *Sergeant* was operated with two men on a watch. During the operation of the vessel, five new operating engineers were readily trained, on the ship, and served as replacements.

The ship's engineers who operated the *Sergeant*, even though it was a compromise plant, preferred the gas-turbine plant to steam plants they had operated. The ship's force, both engine and deck, had the utmost confidence in the plant. Maneuverability of the vessel, as a result of the gas turbine and variable-pitch-propeller combination, is far superior to that of conventionally propelled single-screw ships. This is particularly evident during docking and undocking operations.

During the operation of the *Sergeant* a large number of representatives of shipping companies and engine manufacturers, both domestic and foreign, visited the vessel. Practically all of them looked with disfavor at the equipment necessary to test, clean, and treat residual fuel aboard ship. In their minds they were immediately ready to associate far more difficulties with the fuel-processing system, than was ever actually encountered in service. In addition, since most of the foreign visitors were either diesel-engine operators or builders, they seemed reluctant to accept, as fact, the extremely low maintenance on the gas turbine reported to them by the ship's engineers. They seemed immediately to assume that a gas turbine operating on residual fuel would have the high maintenance they are familiar with in diesels operating on intermediate and residual fuels.

Fuel cleaning and treatment were the only special problems. Both the fuel washing and additive systems have performed as intended. There is no denying that these systems (as installed in the *Sergeant*) required careful and continuous attendance on the part of the operating personnel. The end result has certainly justified the means. After the initial "bugs" were worked out of the wash system, it was trouble-free. The additive system gave no trouble at any time. Examination of the turbine and combustion system showed that with desalted and inhibited residual fuel the gas turbine can be a very low maintenance marine-propulsion unit. It also showed that corrosionwise, the condition of the unit was very nearly as good as it would have been had the gas turbine operated on an ideal fuel such as natural gas.

TABLE I—*Bunker C Fuels Washed—Original Properties*

Port of Supply	A.P.I.	Visc. SSF/122°F	S-%	NA-PPM	V-PPM
Southampton	15.5	136	3.79	56	54
Augusta	15.6	177	3.54	42	46
Trieste	18.3	58.4	2.94	5	36
Bari	-	50.8	2.69	30	26
Antwerp	12.9	135	3.58	14	40
LeHavre	14.2	139	3.48	54	58
Leghorn	15.3	176	3.40	12	42
Aruba	13.5	175	2.07	60	355
*New York (by special arrangement)	18.9	88	1.55	15	60
*Bordeaux	18.3	58.4	-	20	60

NOTE: * Denotes fuels washed on vessel.

Any residual fuel that can be properly desalted can be burned in the gas turbine provided sufficient inhibitor is added to it. Table I lists bunker C fuels that have been successfully washed and their properties. The average sodium content of the fuel after washing aboard the *Sergeant* was 2.5 ppm or less.

The control system of the gas turbine in the *Sergeant* was a completely new design, and initially required minor modifications. After these guarantee changes were made, the control system proved fully as reliable as the governing system of a steam turbogenerator.

The bridge control was intially installed to test out remote gas-turbine control. It was felt that improved maneuvering could be gained for docking and undocking operations, and would permit bridge operation at sea in an emergency.

The bridge control was not used except for trial tests. It was found that because of the lag in energy build up in the regenerators it was necessary to make compensation with the fuel lever to obtain the desired ship response. This compensation was best made by reading and interpreting certain engine-room instruments. To make the bridge control practical either of two requirements are needed:

a) The existing instruments on the bridge show propeller rpm and gas-turbine exhaust temperature. Additional instruments such as compressor rpm, compressor discharge pressure, second-stage nozzle position indicator would be required on the bridge as well as an operator to interpret the readings and make the necessary fuel-lever adjustment to compensate for regenerator lag.

b) Another function added to the governing system that would take a speed signal from the power turbine (used only while maneuvering) and utilize it to maintain a preset low-pressure turbine speed as energy builds up in the regenerator, would make the bridge control adequate for completely automatic maneuvering.

SHIP'S FORCE MAINTENANCE

The fuel nozzles were cleaned once every round trip voyage (roughly 700 hours). At no time were these nozzles actually in need of cleaning. The nozzles were cleaned only because it was felt that this was good practice.

It was routine to clean the compressor and turbines by water washing after each long sea passage. Major sea passages averaged 10 days duration. The washing of the compressor and turbines was a simple operation taking less than 3 hours to complete. The compressor was washed (while being cranked at 1400 rpm) through spray heads permanently fitted in the inlet ducting. To wash the turbines one of the fuel nozzles was removed and a hose inserted in a combustion chamber. With the high-pressure turbine being turned by the cranking turbine, and the low-pressure turbine being turned by the jacking gear, the turbine rotors are washed until the turbine drains run clear water.

The washing of the compressor has always removed the dirt and salt deposits from it, and restored it to the design efficiency. Since the fuel additive deposit left in the turbines is water soluble the water washing completely removes it, and restores the turbines to design efficiency.

On the maiden voyage some power loss was experienced with salt spray fouling of the compressor. Vestibules were added to the main air intakes to prevent induction of heavy salt spray under severe weather and ship roll conditions. After this structural change was made salt spray fouling ceased to be a problem, and the fouling from salt-laden air in a 10-day passage was negligible.

GAS-TURBINE INSPECTION RESULTS

At the completion of this project, and to obtain maximum benefit from this operating experience, a decision was made by the Maritime Administration to inspect the gas-turbine unit. The inspection was directed to those parts that are unique to the gas turbine; in general, the "hot" parts, or gas-path parts, and the axial-flow compressor. Figure 2 is a cross-sectional view of the gas turbine, and indicates the areas included in this inspection.

In an inspection of this type, it must be remembered that the condition of parts, or life of part, is a function of type of service. The type of fuel burned is significant, with residual oil representing the most severe condition as compared to diesel fuel or natural gas. The number of starts is significant due to the "thermal shocks" that accompany each start or stop. As noted earlier in the paper, the starts were frequent. The load cycle is significant, with relatively constant load representing the best condition, and frequent and large load changes representing the more severe condition. As would be expected in a marine application of this type, most of the operating hours are at sea with relatively constant load.

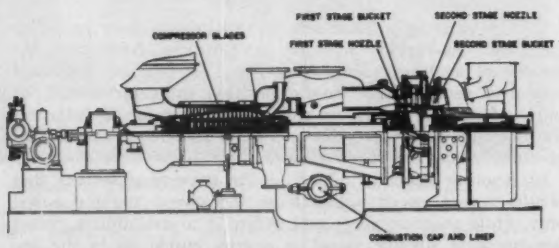


Figure 2. Cross section of gas turbine showing location of major parts inspected.

Axial-Flow Compressor

Prior to this inspection, and in keeping with normal operating procedures, the compressor blading was washed with fresh water while being cranked at approximately 1400 rpm. Figure 3 shows the compressor blading as inspected; the upper casing was not fully removed. The blading showed very slight signs of erosion on the forward face, probably as the result of various abrasives inducted with the inlet air.

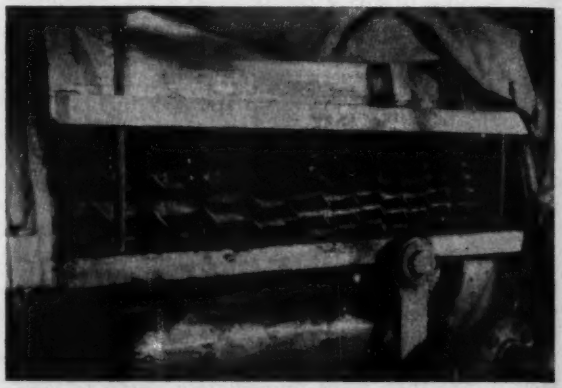


Figure 3. Axial-flow compressor rotor blading at 9270 service hours in ship.

Slight mechanical damage was noted. One second-stage blade had a 1/32-inch dent on the leading edge; four ninth-stage blades showed 3/32-inch dents on the leading edge. The source of this damage was not determined.

The only indication of corrosion evident was light pitting near the base of the tenth-stage rotor blades. The inlet guide vanes were covered with a light coat (0.003 to 0.008 in.) of black scale and dirt.

All other blading inspected was found to be free from evidence of rubbing, corrosion, mechanical damage or deposits. The compressor section was considered to be in excellent condition and can be returned to service without repair or replacement.

Combustion System

Figure 4 shows the combustion liner as inspected, and Figure 5 is the combustion cap as inspected. The liner is in almost perfect condition with no

Figure 4. Combustion liner after 9270 service hours in ship.

louver cracks, no distortion, and only a minor amount of galling at the liner discharge where it makes a slip fit with the transition piece, The cap is also in excellent condition with one small area of corrosion on the downstream edge of the cylindrical piece, and two welds cracked on the fuel-nozzle bushing. Corrosion of both parts, although present, resulted in very little discernible loss of metal.

Three significant factors affecting life of parts were listed earlier in this paper. In the case of these combustion parts, there are other significant considerations. The combustion headers are designed and arranged to provide good air distribution among the combustion chambers and good approach conditions to each chamber. Fuel flow to each combustion chamber is matched by a positive-displacement pump to give equal loading to each chamber. A feature of the two-shaft, variable second-stage nozzle machine is the ability to vary the output horsepower by changing compressor speed and maintaining relatively constant firing temperature; thus temperature changes in the combustion system are minimized.

The condition of fuel nozzles affects combustion chamber life. Maintenance on these nozzles was discussed earlier in this paper. The combustion system can be returned to service without repair or replacement.

First-Stage Nozzle

A detailed examination was made on the upper half of this nozzle ring. No corrosive attack could be detected at any point on the partitions. This was emphasized by the observation that original test

Figure 5. Combustion cap after 9270 service hours in ship.

impact probes on the partition leading edge were still sharp and showed no signs of deterioration. Also the trailing-edge thicknesses were all within the original tolerance.

There was no trailing-edge distortion whatsoever, but a total of 22 trailing-edge cracks were noted in 21 partitions, generally located toward the outer diameter. The maximum number of cracks in any partition was three, and the cracks did not exceed 0.375 inches in length. These cracks are thermally induced, and are somewhat a function of number of starts. This condition requires no repair unless cracks extend further axially or turn radially. Both inner and outer partition rings were in good condition, and there was no indication of combustion-gas leakage through these rings.

A material sample was removed from the trailing edge of one partition, and a metallographic examination was made. As all of the partitions in this upper-half nozzle ring appeared to be in the same condition, it was concluded that this sample was typical of all partitions in the first-stage nozzle.

Examination of the sample and hardness checks indicate that the trailing edge of this partition operated at an average temperature between 1400 and 1500 F (design firing temperature 1450 F). Intergranular penetration in the metal was slight, being 0.004 inches mean and 0.010 inches maximum. The nozzle assembly can be returned to service without repair or replacement.

Second-Stage Nozzle

The second-stage-nozzle partitions were examined without removing from the turbine shell. These partitions were found to be in very good condition with no evidence of mechanical damage or corrosion.

Turbine Buckets

Liquid-penetrant tests were performed on first and second-stage buckets. All turbine buckets were found free of cracks, and still maintained their orig-

inal cold clearance in the dovetail attachment at the turbine wheel. The dovetail attachment was partially visible. This area was found to be clean, bright, and free of cracking, thus confirming design expectations of the wheel cooling air system. All turbine buckets were found to be sound and free from physical damage.

Prior to this inspection, the turbine buckets were washed with fresh water to remove oil-ash deposits. After washing, all oil-ash deposits were removed except for a hard adhering scale found on all second-stage buckets. This deposit was hard and magnetic. A spectrographic analysis revealed the following constituents:

	Per cent		Per cent
Iron .....(approx.)	10	Silicon	0.3
Chromium	6.0	Manganese	0.3
Vanadium	1.4	Nickel	0.18
Magnesium	0.6	Molybdenum	0.12

This scale is principally the result of oxidation of the buckets, although the magnesium and vanadium content results from the treated oil products of combustion. It is believed that this scale is shucked or sluffed off at each startup due to rapid temperature changes on the bucket surface.

Gas Path

Figure 6 shows the over-all turbine area including first and second-stage buckets and the hot-gas path. The entire area was found to be in good condition and requires no repair or replacement.

EVALUATION OF RESULTS OF INSPECTION

Detailed examination and analysis of the condition of critical hot parts of the gas turbine unit after 9270 hours of marine operation show that no repairs or replacements are required. It is, therefore, possible to estimate a schedule of future maintenance for these critical parts as shown in Table 2. Auxiliary equipment of the gas-turbine unit such as the attached fuel, lube and cooling-water pumps, and governor system will require routine and normal maintenance comparable to similar type equipment found in conventional drives.

Figure 6. General view of turbine area after 9270 service hours in ship, showing turbine buckets, interstage gas path, and combustion transition piece (nozzles removed).

DESIGN IMPROVEMENTS FOR NEW SHIPS

In addition to the compressor washing and grit-cleaning systems, similar provisions are recommended for the turbine. Figure 7 shows a sketch of both a built-in turbine water-washing arrangement and a turbine grit-cleaning system. The washing system would facilitate washing the turbines in port and also insure a more thorough washing of the combustion caps, liners, and piping. The grit-cleaning system would be necessary for operation on higher vanadium fuels where additive plugging of the turbines may require cleaning under load to maintain satisfactory turbine efficiency.

Although it was never necessary to change out a fuel nozzle under load, it is felt that this is a desirable feature. It is possible to do this on the *Sergeant*, but the construction of this removable nozzle assembly could be simplified.

The "come home" emergency turbine proved to be unnecessary and should be eliminated. In a single-screw ship an attached ship's service generator could be installed and arranged to serve as an emergency propulsion motor in the event of a main

TABLE 2—*Expected Repairs on Critical Components of John Sergeant Gas Turbine*

4 Yr. Periodic Engine Survey Estimated Hours	Comp. Blades	Tb. whls. w/o Buckets	1st stg. Nozzle	1st stg. Buckets	2nd stg. Nozzle	2nd stg. Buckets	Combustion Liners & Caps
No. 1 Survey 20,000 Hours	0	0	Minor Repairs	0	0	0	Replace
No. 2 Survey 40,000 Hours	0	0	Replace	Note 1	0	0	Replace
No. 3 Survey 60,000 Hours	0	0	Minor Repairs	0	0	0	Replace
No. 4 Survey 80,000 Hours	0	0	Replace	Note 1	0	0	Replace

Note 1—Replacement possible and dependent on condition found at time of survey. Replacement of buckets can be made in place and without rotor removal.

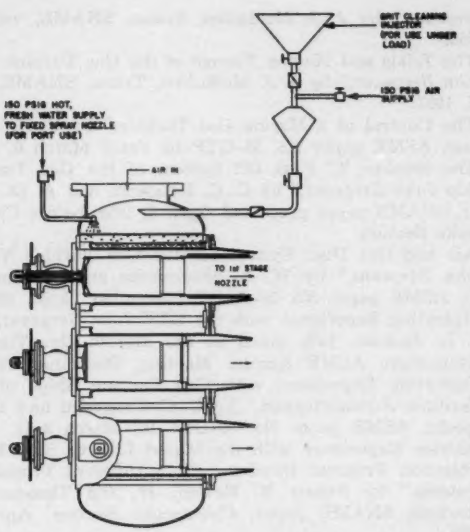

GRIT CLEANING INJECTOR (FOR USE UNDER LOAD)
150 PSIG AIR SUPPLY
150 PSIG HOT, FRESH WATER SUPPLY TO FIXED SPRAY NOZZLE (FOR PORT USE)
AIR IN
TO 1st STAGE NOZZLE

Figure 7. Built-in fresh-water turbine wash and grit-cleaning systems.

unit casualty with power supplied from the required stand-by generators.

TABLE 3—*Evaluation of Gas Turbine Unit Performance*

	Expected	Actual
SHP (normal)	6,000	6,100 (approx.)
Overload potential (SHP)	7,500	in excess of 7,500
Ship's specific fuel	.538	.522
Lube oil cons.	nil	1.0 gal/day
Ability to use low vanadium residual fuels	good	excellent
Availability	high	99.7%
Maintenance	low	low
Crew watch	2	2
Overtime	normal	normal
Response to controls	excellent	excellent

To reduce cost, weight, and for simplicity, the lube-oil gravity-tank system and its controls should be eliminated. An attached lube-oil pump to serve both the gas turbine and double-reduction gear should be provided. The stand-by electric-driven lube-oil pump should be on battery back up.

The shaft-brake system on the *Sergeant* did not prove adequate. It would appear that a zero power condition can be achieved by blowing off sufficient gas ahead of the load turbine, or similar arrangement, and should be investigated. This system would eliminate the objectionable features of a friction brake in bringing the load turbine to rest, and would be relatively maintenance free.

Considering an unmanned engine room, battery back up should be provided for the gas-turbine controls, including all the electrically driven vital propulsion auxiliaries such as:

a) Lube-oil pumps.
b) Fuel-oil booster and additive pumps.
c) Fuel-oil dispersator.
d) Cooling-water pumps.

Shipboard arrangement of the gas turbine piping, and ducting should be made to facilitate inspection and maintenance of the gas-turbine components. The regenerator should be located preferably below the gas turbine both for improved ship stability, and to eliminate the need for dismantling ductwork when the gas turbine is opened for inspection and maintenance.

Elimination of the steam starting turbine is recommended, and electric motor cranking should be provided in its place.

Increased clean-oil storage should be provided, sufficient for at least 10 days of full-power operation. This would greatly reduce normal crew overtime and further increase clean-oil operation reliability.

Advantage should be taken of all the latest developments to further improve efficiency and ease of operation. Some of these developments are as follows:

a) Use of magnesium-oxide fuel additive to reduce handling and storage to a minimum.
b) Use of latest technology to provide a completely integrated package fuel-washing system.
c) Use of higher temperature cycles.

Evaluation of Gas-Turbine Unit Performance

Table 3 shows a comparison between expected performance and actual performance.

CONCLUSIONS

Service experience of the gas turbine in the *John Sergeant* has demonstrated its high adaptability and favorable potential for a marine drive. Low-vanadium residual fuels are readily handled with an on-board fuel-treatment system and availability of satisfactory residual fuels in several European bunkering ports has greatly broadened the operating range of a gas-turbine ship.

The *John Sergeant* has demonstrated the practicability of operating a residual-oil-burning gas-turbine plant with two men per watch, even considering the unfavorable washing arrangements imposed by conversion compromises in this project. It was found that only the fuel-oil-treatment system required continuous attention by a watch stander.

A fuel-oil-treatment system with improved arrangements and designed to be fully automatic would permit operation of the *Sergeant* with one man per watch.

The *Sergeant* could be operated with no engine-room watch standers by supplying prewashed and pretreated residual oil to the ship or by the use of the lowest grade distillate fuel that meets fuel-oil specifications.

The superior operating characteristics shown by the *Sergeant*, and especially its adaptability to re-

duce crew costs, leads the authors to conclude that unless nuclear propulsion succeeds in displacing all large conventional marine drives the application of the marine combustion gas turbine has a very promising future.

ACKNOWLEDGMENTS

The authors wish to express their appreciation for the many helpful contributions they have received and give special recognition to J. Gross who prepared an excellent detailed report during this inspection, A. D. Foster who made a detailed inspection and report on specific parts, and for the contributions of the Esso Research and Engineering Company. Our thanks particularly to the excellent co-operation and support received throughout this gas-turbine project from Messrs. W. Rand, J. F. Devlin, S. J. Topping, J. C. Cragin, and N. Bachko of the United States Lines.

REFERENCES

1. "The Gas Turbine Installation in the Liberty Ship *John Sergeant*," by J. J. McMullen, Trans., SNAME, vol. 63, 1955.
2. "The Trials and Maiden Voyage of the Gas Turbine Ship *John Sergeant*," by J. J. McMullen, Trans., SNAME, vol. 65, 1957.
3. "The Control of a Marine Gas Turbine," by F. H. VanNest, ASME paper No. 58-GTP-10, dated March 6, 1958.
4. "The Bunker 'C' Fuel Oil System of the Gas Turbine Ship *John Sergeant*," by C. C. Tangerini and A. D. Foster, SNAME paper presented April 3, 1958, before Chesapeake Section.
5. "Air and Gas Duct System for the Gas Turbine Vessel *John Sergeant*," by W. A. Sherbrooke and H. Monroe, Jr., ASME paper No. 56-A-207, November 25-30, 1956.
6. "Operating Experience with the GTV *John Sergeant*," by R. L. Jackson, talk given at the Marine Gas Turbine Symposium, ASME Annual Meeting, December 1958.
7. "Operating Experience with Gas Turbine Ships of the Maritime Administration," by C. C. Tangerini and D. H. Specht, ASME paper No. 59-GTP-16; March 8-11, 1959.
8. "Service Experience with the Marad Liberty Ship Modernization Program Involving Four Different Propulsion Systems," by Robert Y. Newell, Jr. and Theodore J. Chwirut; SNAME paper, Chesapeake Section, April 2, 1959.

SURVIVAL TO DEPEND ON SPLIT-SECOND CALCULATIONS OF ELECTRONIC BRAINS IN EVENT OF MISSILE ATTACK

American military commanders would have the information necessary to launch a retaliatory attack only ten seconds after the first enemy missile is detected in the event of a sneak attack upon the United States and Canada, it was revealed on 19 October 1960. This is all the time that is needed by the complex electronic data processing equipments of the Air Force's Ballistic Missile Early Warning System (BMEWS) to determine speeds, trajectories, time and area of impact, and the points of enemy launches.

In an address to the Institute of Radio Engineers, Mr. James E. Sloan of the Radio Corporation of America stated that because of the fantastic speed of the data processing equipment vital alarm level information is made available to U. S. Strategic Commanders so that our retaliatory forces can be on the way to designated enemy targets before the first hostile ICBM hits American soil.

"In the past, warning and retaliation have been measured in hours and minutes," Mr. Sloan told the IRE gathering. "However, in today's space age, with ICBM's traveling at speed exceeding 15,000 miles per hour, action for our survival will be accomplished in seconds.

"If we were to be attacked today from beyond the northern polar region the radar data takeoff and missile impact prediction computers of BMEWS would make split second calculations which would be instantaneously transmitted to NORAD at Colorado Springs and SAC at Omaha. At these vital combat operation centers another computer, the display information processer would process the information in a few seconds so that it can be made available to our military commanders on the strategic displays at NORAD and SAC. All of this, from the moment the missile is detected takes less than ten seconds."

E. B. HINCKS and R. W. BRAGG

INFORMATION FOR DIRECTING SPACE AND MISSILE PROGRAM

THE AUTHORS

Mr. E. B. Hincks is a Director of Research for the Industry Planning Service of the Aerospace Industries Association. Previous positions have been with the National Security Resources Board and the Bureau of the Budget.

Mr. R. W. Bragg is an industrial consultant specializing in Research and Development programs with prior Government experience in the Research and Development Board, Office of the Secretary of Defense, and Naval Weapons Research and Development.

THAT THE predictable impediment to successful advanced missile and space programs is not technology but is organization and administration has been attributed to the late John Von Neumann. Devising helpful rather than impeding techniques constitutes the most urgent and demanding challenge to management staffs today. The following paragraphs concentrate on the informational aspects of organization and administration.

NEEDED—BETTER INFORMATION:

Ideally, budgeting and auditing, reporting and program review of men at work in scientific programs should assist the advance of technology at every level.

Management staffs can contribute by making available pertinent and timely information for decisions by scientists and by those responsible for allocating resources. Decisions, both scientific and economic are never consistently better than the information on which they are based. Poor management decisions have, unhappily, compounded the troubles of this country's military hardware development programs; poor information and information gaps, as well as excessive quantities of irrelevant information, have also been contributing factors.

Von Neumann's warning of the threat to advanced missile and space systems reflects his awareness that the on-coming missile and space programs differ fundamentally from currently successful mass production programs, such as steel, transistors, ball bearings, telephone equipment, and automobiles. Since organization and administration reflect the nature of the basic activities being performed, a brief analysis of these differences is presented.

DEVELOPMENT PROGRAMS VS MASS PRODUCTION

Missile and space programs are essentially developmental, with a "one-of-a-kind" product; mass production is essentially repetition of nearly identical cycles of work with multiple like products. The number of units planned for production in missile and space programs is small compared to mass production programs.

Along with the differences in production activities inherent in the different number of units produced, are differences in the magnitude of changes in the physical specifications of units produced sequentially. "Product Improvement" in mass production is evolutionary, accomplished by introducing marginally improved machine or process or raw material. Between successive blocks of production of one missile, there are revolutionary changes. The extent of this is attested by the missile fraternity's motto: "If it works, it's obsolete."

TO THE UNKNOWN THROUGH THE FAMILIAR

These sharp performance characteristic changes between successive models of one missile should not obscure the working process by which they are accomplished. The bulk of the operations performed by all the sub-units of a development program are within the state-of-the-art known when the program is initiated. An aggregation of known and tested steps, with the addition of a restricted number of novelties from the laboratories, results in a new missile or spacecraft with startingly different performance. Because so much is known and because the unknowns can be isolated, management staffs can contribute a useful information structure.

INFORMATION ON REPETITIVE WORK CYCLES

Historically in the mass-production processes, the procedures of budgeting, reporting, and programming have been developed and applied so as to enhance management control. Information about the production process has been recorded, gathered, and reduced, becoming an essential part of decision-making. During the last half century, work measurement, time and motion studies, job and quality standards of all kinds, including costs, have been developed by observation of men working and by introducing refinements in processes as the work cycle is repeated again and again. The capacity of human beings and machines to do physical work has thus been measured and codified so that reasonable estimates in these areas may be made concerning the time required, equipment needed, physical specifications of the output, and costs anticipated for analogous future work.

Where the physical specifications of the product to be developed and made represent a quantitative jump over the specifications of existing items, such as a new generation missile compared with an operational missile, there is currently no generally accepted set of procedures and data that will produce demonstrable estimates of time required, equipment needed, and of costs.

DESCRIPTION AND MEASUREMENT AS PRIME REQUIREMENTS

There are two prime requirements in the field of information for management in any program—development or mass production—which must be met if rational decisions are to be made, if management is to be recognized as a help rather than a hindrance to getting the job done. The first requirement is a written description of the program in terms of final product desired, quantity and quality, time phasing and cost. The second is the continuing measurement of day-to-day milestones passed, amounts expended, and physical quantity and quality of each piece part and assembly made. The measurement of events and physical qualities and the units of measure in which they are recorded are the raw material of the informational structure. What to measure and units of measure to be used must be specified in advance, so that, as work progresses, numbers are generated which will fit into analyses of status, potential trade-offs among time-cost-performance and reliability, and predictions of levels of accomplishment in each of these interrelated areas.

Essentially, these two requirements are necessary if data about day-to-day operations are to provide the basis for predicting the future of the program. Useful predictions, particularly those of time and cost, are currently realized, or are realizable with modifications of existing management techniques, accounting practices, and quality controls. However, the current practices in measurement and data reduction, in the opinion of the authors, do not at the present time permit predicting reliability of complex end-items assembled from multiple complicated components. Research is needed in the decade of the 60's to achieve realistic reliability predictions for space hardware.

DESCRIPTION AND MEASUREMENT IN MASS PRODUCTION

In mass production, existing techniques of issuing production orders in objective terms, usually quantitative, recording and reporting the actions of those ordered in the same objective terms and units of measure, committing resources with orders and keeping track of costs, and quality control sampling and charts, meet the test of both requirements—description of objectives, and measurement of accomplishment. In repetitive programs the steps between the order and the accomplishment are more or less completely documented before the decision to proceed and before the action starts; cost histories and physical quality standards are available. The documentation is essentially in the form of specifying a step, and the associated quantities, that must precede by so many days or months the completion date. Each step, its quantities, cost, physical

tolerances, and timing, cumulate into the whole program and such a program is repeatable without much change for varying quantities of output. The sequence of the actions to be taken, as well as the individual actions themselves, are described and documented on the basis of historical data. Results at the end of a cycle can be predicted* with a relatively high degree of confidence at a point in time within the cycle, or before its start.

The challenge to management staffs is in development programs—to provide such an information structure without having as much time-proven historical documentation as in the case of a repetitive production cycle.

DESCRIPTION AND MEASUREMENT IN DEVELOPMENT PROGRAMS

In a development program, the information structure requires a framework from the scientific leadership. The required structure is a conceptional forecast and organization commitment, in outline form, of what the program is to develop (quantity, quality, and performance specifications), with estimated costs, time required, and major interim goals which must be achieved on the way. Documentation by staff of this outline will record program definition in terms of work to be done, adequate to initiate an orderly process of subdividing total effort into smaller units of effort. The subdivision process must be continued (though not for the entire program concurrently) until specific tasks are identified, which closely resemble other known tasks for which documentation exists.

At this point of program subdivision, predictability begins to become possible. A work project, with time, cost, and quality specified quantitatively and objectively, can reasonably be set forth. Management knows it is not asking the impossible, the doers know the boundaries around the task. This type of predictability is important, both in knowing that the job will get done, and in knowing that getting the detailed job done will contribute to reaching the long-range program objective.

Thus, the first requirement mentioned above, can be met, in part and with increasing resolution over time, by subdividing the scientists' total program until "predictable" work assignments are reached. Unlike a mass-production cycle, however, this degree of subdivision cannot be documented for the entire program initially. Large gaps must of necessity be left. A year or more in the future shows a decline in detail which reflects contingencies, as yet unresolved, because intervening steps are still to be taken. Subdividing to "predictable" work assignments is a continuing process, within the framework of the entire program.

Again in the case of development programs, the second requirement, day-to-day measurement for predicting, trading-off, and internal readjustments, can be met by internal procedures. For each work assignment that is underway, actions taken are recorded along with amounts spent and the physical characteristics of the product being worked on. These measurements are pursuant to a pattern centrally specified in advance. Records must be cumulated centrally, and the data reduced for comparison with the orders starting each work assignment, and for other analyses.

THE INFORMATION STRUCTURE

Preparing documentation of the proposed steps in development programs, with associated time-cost-performance and reliability magnitudes, and establishing the necessary records and procedures are the areas in which management staffs are creating new methods today. Current work can be summarized as:

Program Forecast: A written description outlining what is to be accomplished and the total effort contemplated, showing the participations of organizations in terms of start times and completion times for the role of each, with the major events to be accomplished specified by calendar dates. This documentation includes cost estimates for major subdivisions of effort as well as total estimated cost, and shows the interrelationships among organizations in their several contributions to the final objective.

> Within each participating organization, including the one having top program management responsibility the following are essential:

Record of Events and Up-dating Forecast of:

As the project is worked on, (a) gathering and displaying the historical record of achievement with dates of accomplishment of stated interim objectives and related actual and physical descriptions of outputs, and (b) as the project matures, revising the remaining forecast with appropriate fill-in of detailed objectives and work assignments for the near future with related revised cost estimates and resource commitments.

Work Assignments and Resource Commitments:

Established method of record, consistently used, for ordering a named unit of the organization to carry on activities necessary to accomplish a named objective by a certain calendar date, identifying the objective in terms of events set forth in the current advance outline or network, and for authorizing the use of specified quantities of resources (men, dollars, materials, facilities) as a concurrent organization commitment.

Upstream Reporting:

Established method of record, also consistently used, for the individual named in such an order to

* In the area of reliability, most effort has been devoted to predicting piece part characteristics. Relatively little has been published on assessing the reliability of assemblies from data on constituent piece parts.

report directly to the orderer any occurrence as it happens, which in his judgment affects prior estimates of time of delivery, or the adequacy of the authorized resources commitment or likelihood of the physical nature of the product under development falling outside specified tolerances. Reported events include the accomplishment of interim objectives as they are achieved. Use of resources is not reported through this channel.

Cost Accounting:

Cost accounting systems to relate actual costs to work authorizations, providing total project cost as a summary of costs accumulated to individual authorizations and having available subtotals related to appropriate groupings of authorizations and subtotals of categories of cost.

SOME ANALYSES FROM THE INFORMATION STRUCTURE

Specifying units of measure and what shall be measured in each program assures the development of compatible data for decision-makers. The mass of data in any sizeable program must be brought to manageable compass by reduction through studies and analyses. Although beyond the scope of this paper, it is useful to indicate some of the analyses for whose preparation the information system is designed and operated.

Selection of One Program from Competing Proposals:

Since resources are limited, the cost of the means to accomplish a given mission, including the hardware, is critically important in selecting which program to fund for a given mission. The proposed magnitudes of time, cost, performance, and reliability, as estimated by competing contractors, must be in such terms and units of measure as to be used directly by those evaluating alternate means of completing missions. Where this can be accomplished, a value basis is provided for choices between competing proposals, even though the hardware involved may be dissimilar.

Program Progress:

After funds are committed to a specific development, the information system herein described provides the basis for assessing program progress, and for isolating potential trouble spots in time for remedial action to be taken. This type of analysis is critical when multiple organizations each have dovetailing responsibilities to produce a final complex system.

Trade-Offs Between Time-Cost-Performance and Reliability:

The trade-off concept flows from the inevitable changes that are made as a development program matures. At any stage in the work, the targets of time, cost, reliability, or performance may be revalued as too low or too high or out of balance. If the dollar cost appears too high, the program can be stretched out in time for example as a trade-off with the performance and reliability targets held constant. Within fixed limits of time and cost, performance goals may be raised, with a trade-off in relaxing reliability. When the targets are out of balance beyond the limits of tolerable trade-off, a Stop-Loss is clearly indicated. It should be noted that the "out of balance" of the targets may not reflect on anything in the program under consideration, but upon developments in other collateral programs, or budget cuts imposed by higher authority. In any event, the information structure under discussion is designed to provide the data for assessing potential trade-offs on a quantitative basis.

Predicting Accomplishment-Cost-Performance and Reliability:

These predictions are of fundamental importance for effective system management. The adequacy with which these predictions can be made is an important measure of the quality of the information system. It should be noted, however, that the information generated within any development program can only handle factors within the program. Insofar as the program is affected by external factors, separate but compatible treatment is required.

Furthermore, as of today, predicting reliability of complicated missiles and space vehicles in the early development stages lacks adequate formulation and methodology as noted above.

Stop-Loss Analysis:

At any time, the expected completion of a program may be judged of marginal value in terms of predicted time-cost-performance and reliability. This judgment may arise from external causes, such as new missions, break-throughs in other programs, and funding changes. This judgment may also result from analyses internal to the program, such as predictions of levels of future program accomplishments and trade-off studies.

Whatever causes the judgment that the value of completing the project is marginal, the information structure should provide for a separate Stop-Loss analysis. The implications of a decision to stop are so far reaching that an audit study is warranted. In the continuing battle for funds, a stop-loss analysis which displays the quantitative implications of program cancellation has defensive value for any program and conservative value for the economy.

Step-By-Step Resolution:

In the early stages of a development program, the starting conditions and the ultimate desired goals are usually understood in significantly greater detail than are the program steps in between. The current facts as to available funds, the state-of-the-art, and the near-term rates at which resources can be made available, are generally known. The ultimate objectives of the program are often specific,

reflecting the user organization's operational needs some years in the future, without respect to precise methods for meeting them.

The lack of information between the beginning and the end of the program is normal and to be expected. Part of the lack of specific information is due to the absence of knowledge which will be obtained as the work progresses, and part of it is due to the inability to predict the detailed results of work not yet done.

An information structure is essential for the orderly resolution of these unknowns, step-by-step. Detailed schedules for near-term future work are developed within an informational framework of the ultimate goals. As the program matures, the historical data are assembled concerning immediate past accomplishments; these data make possible increasing detail in the specifications of realistic next steps. Hence the structure provides the basis for adding the best judgment of how to reach the targets.

CONCLUSION—THE PRIMARY ROLE OF SCIENTIFIC LEADERSHIP

The discerning reader will recognize the primary role of scientific leadership throughout the foregoing discussion. The Program Forecast is basically a recording of the technical concept of the work involved to reach the goals set forth, within acceptable confidence limits for eventual success, which has been coordinated with executive management and is supported by the latter as an organization commitment. All other aspects of the information structure stem from this original statement.

The judgment displayed in the Program Forecast exists, qualitatively, in the initial phases of every development program under present practice, with quantitative understanding among management of at least the orders of magnitude of effort contemplated. It is the recording of this judgment and understanding, with time-cost-performance and reliability in explicit scalar terms, which has been missing all too often.

It is the thesis of the authors that responsible scientists will receive, appreciatively, a management staff contribution which reduces the original judgment and understanding to writing and builds an information structure thereon that will meet the communication needs of the scientists with minimum demands on their participating time and which will, concurrently, meet the analytical needs of other decision-makers, such as those who control the allocation of resources.

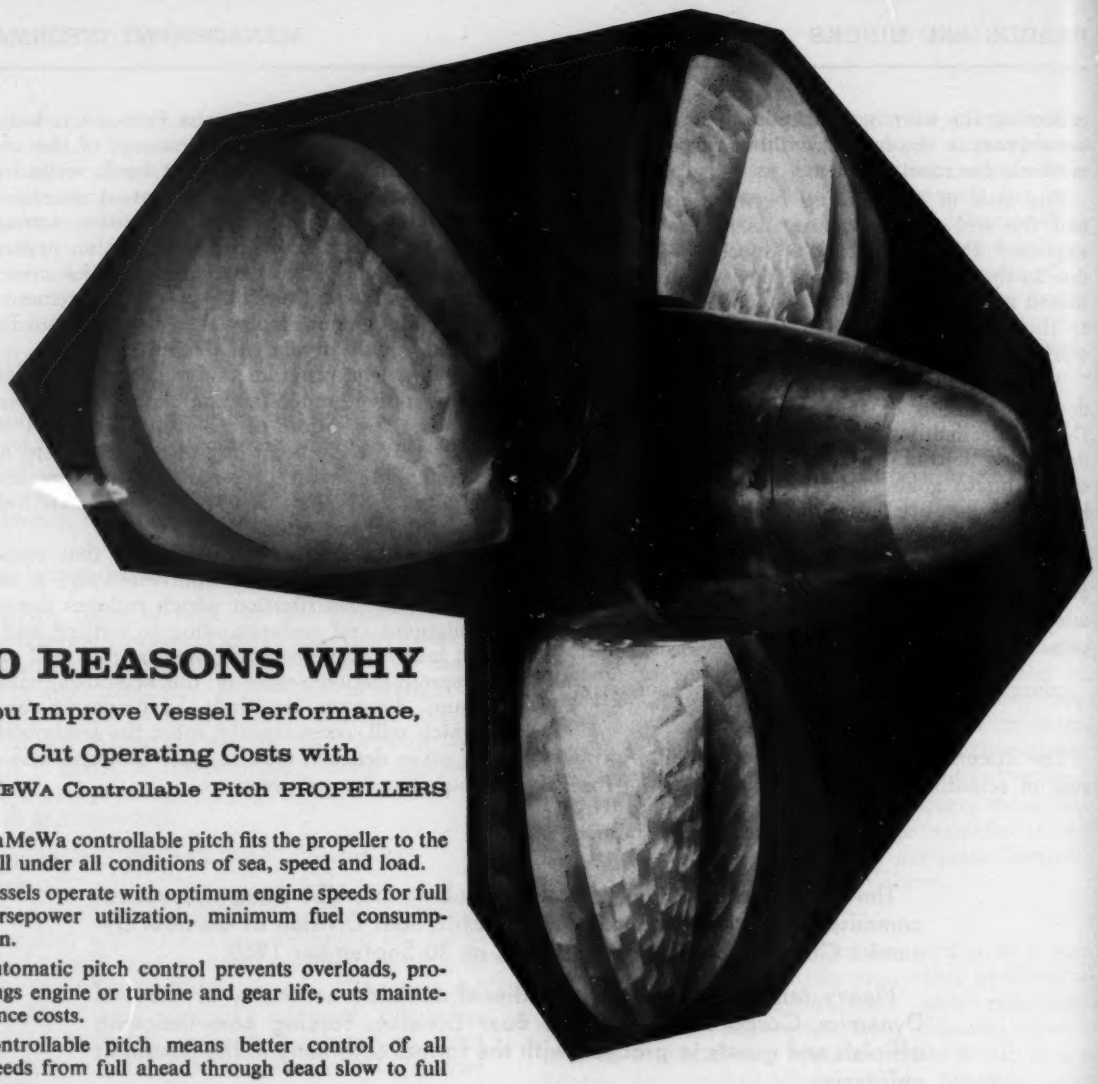
The Navy's second nuclear-powered submarine, USS *Seawolf*, was recommissioned by telephone, at the Electric Boat Division of General Dynamics Corporation at Groton, Conn. on 30 September 1960.

Heavy rains prevented the traditional dockside ceremony at General Dynamics Corporation's Electric Boat Division, forcing commissioning officials and guests to proceed with the formal ceremony in the Division's cafeteria.

As Vice Adm. Charles Wellborn, Jr., Commandant of the Third Naval District, read the orders placing the high-speed attack submarine in commission, the word was relayed by phone to the ship where the ensign, union jack and commissioning pennant were hoisted.

Four former *Seawolf* commanders were on hand for the re-commissioning and the *Seawolf* was welcomed back into Navy service as a "valuable and badly-needed addition to the Fleet." The event took place just six years after the commissioning of the USS *Nautilus*, first of the A-subs.

The *Seawolf* was launched at Electric Boat Division on July 21, 1955, and commissioned originally on March 30, 1957. She was de-commissioned on March 27, 1959, for a change of atomic power plants after having traveled 71,609 miles and is now equipped with a new pressurized water reactor designed to give greater speed and endurance.



10 REASONS WHY

You Improve Vessel Performance, Cut Operating Costs with KAMEWA Controllable Pitch PROPELLERS

1. KaMeWa controllable pitch fits the propeller to the hull under all conditions of sea, speed and load.
2. Vessels operate with optimum engine speeds for full horsepower utilization, minimum fuel consumption.
3. Automatic pitch control prevents overloads, prolongs engine or turbine and gear life, cuts maintenance costs.
4. Controllable pitch means better control of all speeds from full ahead through dead slow to full astern.
5. Direct bridge control means all maneuvers are sure and prompt — no signaling delays, no possibility of confusion.
6. Better maneuverability and ship handling ease saves time entering, docking, undocking and leaving port or working locks and narrow channels.
7. Better maneuverability also means greater safety, cuts accident costs, damage losses and repair delays.
8. Varying propeller pitch lets you adjust for load and sea conditions — vessels make better speed running light, loaded or in heavy weather.
9. Faster speeds, lower operating costs, less maintenance mean lowest ton-mile costs.
10. More than 500 installations totalling over 1,000,000 horsepower have demonstrated the superiority and complete dependability of KaMeWa Controllable Pitch Propellers in all types of vessels and service.

Ask us to prove the advantages of KaMeWa Controllable Pitch Propellers with detailed facts and figures. For complete information, write Dept. NE, Bird-Johnson Company, South Walpole, Massachusetts.

KAMEWA

Controllable Pitch

PROPELLERS

BIRD-JOHNSON CO.

South Walpole, Massachusetts

Sales Office	In Canada	Pacific Coast
21 West Street	A. Johnson & Co., Ltd.	H. J. Wickert & Co., Inc.
New York 2, N. Y.	P.O. Box 56, Montreal 16	770 Folsom St., San Francisco

LIEUTENANT K. B. SCHUMACHER, USCG

LIQUID METAL HEAT EXCHANGERS

THE AUTHOR

was graduated from the U. S. Coast Guard Academy in 1953. Since that time his assignments have included both deck and engineering duty afloat and command of a Loran Transmitting Station. In June 1960 he completed the three year postgraduate course of Naval Construction and Engineering at Massachusetts Institute of Technology.

LIQUID METAL HEAT exchangers are basically not new in practical applications. Mercury boilers have been in use for commercial power generation since 1922. These generally operate with a high mercury temperature of 950-1050°F (in the vapor stage) and evaporate water at 400 to 600 psi in a mercury condenser. A less sophisticated application, which was initiated more than twenty years ago, is hollow engine exhaust valves which are cooled by sodium. At operating temperatures the sodium (melting point 208°F) is liquid and fills about sixty per cent of the hollow. By splashing as the valve moves, the sodium is quite effective in transferring heat from the hot top of the valve to the stem and on to the valve guide.

More recently, the liquid metal heat exchanger coupled with a nuclear reactor, as used in the submarine *SEAWOLF*, has increased general and specific interest in liquid metals as heat transfer media. This plant used one of a system of sodium-potassium alloys which are gaining in popularity and for which there is a growing body of experience and information. Any and all of the various compositions in this system are generally referred to simply as NaK.

Most important among the reasons for using liquid metals is the fact that their heat transfer coefficients are among the highest known. In addition, they are elementary substances and do not decompose, polymerize, carbonize, etc. These advantages, especially the high heat transfers, are compelling enough to maintain interest even despite the disadvantages and problems which will now be considered.

Wetting

In order to realize the high heat transfer rates possible it is necessary that the liquid metal wet the heat transfer surface. If wetting is not accomplished, and the heat transfer rate designed for is not attained, tube temperatures will soar and failure from overheating can occur in seconds. In the early mercury boilers this was a practical problem which required a great deal of research and testing. In this case this solution is addition of 5×10^{-6} to 1×10^{-3} per cent titanium and 0.002 to 0.012 per cent of magnesium which assures that the mercury wets the steel in the boiler tubes. Other liquid metal and tube combinations have required different treatments.

Corrosion

In agreement with broad and common usage, the attack by liquid metals on the materials of their containers and structural materials will be termed "corrosion" when discussed in its more general sense. When considering specific cases more precise terms will be used. Liquid metals can be classed as alkali (such as NaK) or non-alkali (such as Hg). The alkalis are generally the worst offenders in corrosion as will be seen in the ensuing discussions.

Several mechanisms of liquid metal corrosion are of fairly common type. One of these is a relatively uniform solution attack on the solid surface by the liquid corrodant.

Direct alloying is another common method of attack. This is the interaction of liquid and solid to form surface film or diffusion layers of intermetallic compounds and solid solutions. If tightly held, these may serve as a barrier to further diffusion. They may, however, form as loosely adherent scale which can even encourage further corrosion.

Intergranular penetration is a selective reaction of the liquid metal with minor constituents of a solid. By this mechanism a selective grain-boundary attack can drastically alter the physical properties of a material with relatively little effect on its appearance or weight. Application of a stress to the solid, or the presence of a residual stress such as a welding stress, while it is exposed to liquid metal will often accelerate this type of attack.

Attack may be from corrosion by contaminants rather than by the liquid itself. Oxygen, nitrogen, or carbon, dissolved in the liquid or present in suspension as part of a compound, are examples of such contaminants. The most familiar example is oxygen which may form an oxide coating on the metal. As with direct alloying, this could either discourage or promote further oxidation. Also, it is possible that the film might be continually removed by the fluxing actions of other oxides which might be present.

Corrosion-erosion is the result of attack by flowing or turbulent liquid metal. This involves removal of scale, abrasion by suspended particles, and, in the extreme, cavitation which is a breaking out of minute particles of the solid.

Self-welding is a diffusion bonding or welding of solid metal surfaces to each other. Although actual corrosion plays only a small part, the action is facilitated by contact with an alkali metal and is more vigorous when the metals are held together under pressure. This welding is also intensified by increasing temperature. The possible interference with operation of pumps, valves, and flanged joints may therefore place an upper limit on the temperature at which a system may be operated.

Thermal-gradient transfer, a type of mass transport, is due to coexistence of a sizable thermal coefficient of solubility and a temperature differential. Though the actual solubility might be quite low, large amounts of solid may be dissolved at the zone of higher solubility and precipitated in the zone of lower solubility. In some areas the removal of dissolved materials accelerates corrosion attack. Precipitation of material in other areas may interfere with moving or removable parts, such as valves and flanges, and may actually cause plugging of flow channels. Just how this attack will behave in a given system is very hard to predict from equilibrium solubilities and static tests only. Indeed, these alone may predict that the action would go just the reverse of what is observed in actual systems. There are also certain elements and compounds which accelerate or inhibit this action. Generally, these must be found on a case basis.

Concentration-gradient transfer is another type of mass transfer action. Normally the dissolving of one metal would stop when the liquid became saturated, however the equilibrium may be upset by a second metal with which the dissolved metal can alloy to form solid solutions or compounds in precipitation or surface diffusion layers. These layers also can act as a barrier to the mass transfer if they are properly formed. This mode of attack may be in some way related to and interdependent with thermal-gradient transfer, but the relationship is poorly understood.

Radioactive material transfer is an effect which has been observed in NaK systems contained by stainless steel in nuclear reactors [7]. This is a mass transfer which carries radioactive material from a point of corrosion in a radioactive source to a point of deposit or atom exchange with receiver metal. Its rate is defined as the minimum rate of removal of container metal from a radioactive source, in micrograms per square centimeter per month, which will account for the activity observed in other parts of the system. The corrosion rate of the parts inside the reactor which become radioactive by irradiation may be extremely low, yet very significant amounts of activity may be transferred to other parts which would not normally be expected to be radioactive. Increases in temperature and oxygen content of the NaK increase the transfer rate. Impurities in the steel can increase the radioactivity level from that due to the steel alone. In general, Ag, Sb, Sn and Zn will stay in solution in the NaK once it has been removed from the steel, while Fe, Cr, Ta, Co and Mn will deposit out and leave the system radioactive after draining and flushing. Some inhibitors have been found to reduce the transfer rate.

Electrical effects have been observed in the transfer of dissolved elements in solid and liquid metals under the influence of applied potentials. However, there has been no direct evidence of mass transfer by electrolytic means in any liquid metal heat transfer system. [5]

NaK systems are subject to one peculiar type of action which is only poorly understood. This is the

decarburization of plain carbon steels which have been exposed to NaK at elevated temperatures. Apparently the transition from ferrite to austenite with its lesser rate of carbon diffusion will slow this decarburization, since one observer [5] has noted more rapid weight loss and more extensive decarburization of SAE-1020 steel when exposed to impure NaK in the ferrite region at 700°C than in the austenite region at 800°C.

Because of the many variables and unknowns involved, any laboratory tests to evaluate materials for possible use in liquid metal heat transfer systems should be executed so as to simulate as closely as possible the conditions expected in service. Since the materials of a heat exchanger are never fully homogenous and without flaws, and since the parts formed and joined (especially by welding) are not without stresses and imperfections, these elements should be present in laboratory samples. Also, as indicated earlier, actual flow and thermal-gradient conditions may have a very marked effect and should be duplicated.

Most of the more readily available data on corrosion resistance has been based on the following standards:

Rating	Rate of Attack mils/year
Good	<1
Limited	>1, <10
Poor	>10

It is to be remembered that these ratings will not tell us much about intergranular penetration or the mass transport attacks. This data has been summarized in the *Liquid-Metals Handbook*. [5] For the most part it is based on limited numbers of small-scale laboratory tests. Consequently the information presented should be taken only as a guide by which to eliminate obviously undesirable materials and from which to select materials for further testing in simulated or actual service conditions.

Hazards of Material Failure

In the matter of relative danger of material failures it is again the alkali metals which are the greatest offenders. Being generally more corrosive, they are more likely to cause leaks or plugging of flow passages and consequent burnout of a tube which will allow either escape of the liquid metal or its contamination. At any leak, even a very small seepage, the combination of hot alkali and air is extremely corrosive and can cause further failure in a matter of minutes or even seconds.

Should an alkali such as NaK come into contact with liquid water through leakage or tube failure, the reaction can proceed with explosive violence; however, proper design can allow for this possibility by making the regular relief valve system adequate to handle any over-pressures caused in this way.

At high temperatures, many liquid metals, such as NaK or magnesium, will burst into flame in the presence of air. The only truly effective methods of fighting such a fire are those which smother it by excluding air or oxygen. The more conventional fire fighting apparatus must therefore be discarded and replaced by special gear.

If a failure should occur with no hazard to the system or its operators, there is still the problem of how to effect repairs. There is, of course, the matter of possible contamination of the liquid metal. This is critical since more than 0.020 weight per cent oxygen in a sodium-stainless steel system will accelerate corrosive attack. If the liquid is badly contaminated, it may be best to dispose of it and recharge the system. This wastes the metal, but on the other hand, many purification methods are too costly and complicated for their use to be practical [5]. Beyond this, if the system, or any part of it, must be drained and freed of all liquid metal prior to repairs, additional hazards may be encountered. Since alkali metals can react violently with liquid water or hydrocarbons, it is usually necessary to exercise great care and to employ rather inefficient cleaning methods.

System Heating

In those systems employing liquid metals which are solid at ambient temperatures, the additional problem of heating is encountered. There will always be the difficulty that on shutdown of the system it will have to be heated in all parts containing the liquid metal. For those metals having relatively higher melting points, such as Bismuth (520°F) or Lithium (354°F), there is even greater possibility that during operation certain areas such as valve bodies, pump chambers, elbows, etc. may be just cool enough to cause local solidification and depositing. This can obstruct flow and interfere with moving parts. A variety of heating schemes, all of which complicate the system, are used to suit local conditions. One strong point in the NaK system is that the solidification temperature can be varied from 208°F to 12°F by changing composition toward the eutectic. The compositions most used are those which are liquid at room temperatures.

Hardware Problems

Because of their properties such as corrosion, solidification, viscosity, and high heat transfer rates, liquid metals require special hardware not normally used in other heat exchangers. In the exchanger body itself, the danger of leaks in an alkali metal system usually dictates special type construction.

Particularly in systems using water, it is most general to use some sort of double tube construction with the hot metal in the inside tube [3] [5]. The water may be in the outer tube or perhaps the outer tube would contain a mercury buffer with the water in the exchanger shell. The unit would normally be well instrumented to detect a leak in

any direction and relief venting would be provided to take care of pressure build-up due to a reaction resulting from leaking.

With such high heat transfer rates there are generally very high thermal gradients across the metal in the tubes. This usually requires that all joints be high quality welds, tubes be as thin as possible, and thermal expansion be provided for. These thermal stresses are very difficult to calculate, therefore, in this field theory is rather barren and failure experience is used as the predominant design tool.

In handling the corrosive liquid metals, packless valves have become the order-of-the-day so as to avoid leaks. Bellows-sealed valves, with the bellows welded to the valve have been used extensively and are now commercially available. These valves and bellows are required to be tight to a mass-spectrometer test and are somewhat difficult to maintain in service. Although the bellows may be mechanically cycled in test for about 500 cycles without failure, it is very prone to fatigue failure in service when vibration is present from such sources as valve chatter or machinery vibration.

In the field of pumps a great deal has been done to develop a closed pump which is lubricated by the liquid metal. So far, the problem of galling of bearings surfaces has not been solved. Also, the problem of bearing leakage is still present. This can be solved by allowing liquid metal to leak past the bearing into a chamber filled with inert gas. The gas chamber can be fitted with a labyrinth seal on the pump shaft and the liquid metal can be collected and returned to the system. None of these pumps can be expected to be more than 75 per cent efficient. [7] The above mentioned troubles can be circumvented by using some type of electromagnetic pump which will have no moving parts and thus can be fully sealed. These are adequately described elsewhere [1] [5] and depend basically on having a current flowing in the liquid metal. The electrical resistivity of most practical liquid metals is suitable for use in this type of pump. However, it should be remembered that just as a centrifugal pump designed for salt water will be inefficient in oil, so also might electromagnetic pumps suffer when not pumping the specific metal they were designed for.

CONCLUSION

Fundamentally, the possible high heat transfer rates of liquid metals make them attractive despite their drawbacks. The many forms of attack which can be lumped under the term "corrosion" are so complicated and hard to predict that, when designing a heat exchanger, one should rely on past experience with very similar designs or perform tests which simulate to a high degree all the factors which will influence performance in actual service. In addition, the problems of stress and leakage require a very fine attention to design and fabrication. Joints should be welded and relieved in a manner which leaves minimum residual stresses and non-homogenous material. All hardware such as valves and pumps must be of special type allowing no external leaks and moving parts should be eliminated or minimized whenever practical.

BIBLIOGRAPHY

1. Liquid-Metals Handbook (NAVEXOS P-733), 1 June 1950, A.E.C.—Department of the Navy, Washington, D.C., G.P.O.
2. Some Problems in the Application of Nuclear Propulsion To Naval Vessels, by RADM H. G. Rickover, USN, CAPT T. M. Dunford, USN, Theodore Rockwell III, LCDR W. C. Barnes, USN, and Milton Shaw, Trans. of The Society of Naval Architects and Marine Engineers, 1957.
3. The Design of a Liquid Metal Heated Bayonet Tube Steam Generator, by Frank Boni, *Journal of the American Society of Naval Engineers, Inc.*, May 1958.
4. The Thermodynamics of Liquid Metallic Solutions, by John Chipman and John F. Elliot, Thermodynamics in Physical Metallurgy, p. 102-143, Published by American Society for Metals, Cleveland, Ohio, 1950.
5. Liquid-Metals Handbook (NAVEXOS P-733 Rev.), Second Edition (Revised), January 1954, Department of the Navy, Washington, D.C., G.P.O.
6. Reactor Handbook—Materials: General Properties, U.S.A.E.C., 1955, McGraw-Hill Book Company, Inc.
7. Liquid-Metals Handbook (NAVEXOS P-733), Third Edition, Sodium (NaK) Supplement, 1955, Department of the Navy, Washington, D.C., G.P.O.

NEBOJSA GASPAROVIC

THE PROBLEM OF TWO DIFFERENT SYSTEMS OF MEASURES

THE AUTHOR

obtained a degree of Marine Engineering at the University of Zagreb. For three years he dealt with ship's propulsion machinery and standardization of ship's equipment. He now belongs to the editorial staff of the journal "Brennstoff-Wärme-Kraft." He has published several articles on gas turbines and ship's propulsion systems.

ON THE SUBJECT OF redefining metric equivalents for English measures, Mr. Buchsbaum * made quite a lot of statements by means of which he tried to prove the unscientific standpoint of those tending to adopt a universal system of measurement. By imputing to opponents of the English system of measurements, opinions from which they appear to be a group of feeble minded quacks, but still smart enough to want to undermine the economic power of countries using the English system of measurement, Mr. Buchsbaum calculated to impress the reader not by force of argument or truth, but by beauty of words.

From what we read in Mr. Buchsbaum's proposal the essential difference between the system of units and the system of measures remains confusing. Whether 1 meter as a unit is superior to 1 foot is not in question at all. As per definition 1 meter is to be a ten millionth part of the earth's meridian (which, by the way, is not correct because of the error made when the length of the meridian was calculated, derived from nature. As a unit, 1 foot would do just as well. From this point of view neither of the units appear to have an advantage. The same is valid when we consider grams and pounds as the units of weight. The difference starts to appear only when we pass from *units* to *systems*. Our system of numbers is decimal. So is the metric system. Let us have a look at the English system of measurements: 12 inches = 1 foot, the ratio is duodecimal; 3 feet = 1 yard, the ratio is ternary; and to describe magnitude of the ratio 5280 feet = 1 statute mile would require an enlarged vocabulary. This is similarly the case when treating the weights or any derived measures such as areas, volumes, pressures etc. In marine use we see 1 nautical mile = 10 cables = 1000 fathoms. These are of English origin and the ratio is decimal.

The only deficiency of the English system is due to the ratio of measures which is not decimal. If it were decimal, both systems would be equally good (if we do not take into account the units of electricity). The advantage would be on the English system's side since it has been in use for a longer time. The historical influence of the English system is still felt in the metric system. As an instance, we can cite one horse power which, slightly modified, was adopted by the metric system. *I do not think that a viewpoint which requires for decimal system of numbers a decimal system of measures should be called unscientific.*

Mr. Buchsbaum's style tends to deride and to controvert the assertions which he imputes to those that do not share his view, thus trying to influence those that are poorly acquainted with the subject. For instance, in his article, we can read that followers of the metric system consider it as scientific just because it is European and not native. Such an attitude is absurd. It could not be presented to a scientific forum by anyone who does not want to appear to be stupid.

The principle argument which the followers of the English system can use is that all of their tools, measuring instruments etc. are made to the English system which is also more familiar to persons who use them. A change over to the metric system would mean a great loss which can be estimated, only roughly. A study should be made to determine the

* Buchsbaum, A.: *English and Metric Systems Can Co-Exist Peacefully*, A.S.N.E. Journal 72(1960)2, May, pp. 291-94.

best way for making such a step, which would require a pretty long time having an order of magnitude of 5 to 20 years. Only by such a lengthy period can the economic stability of countries concerned be maintained.

The adoption of the metric system in nuclear engineering by countries which otherwise use the English system is at least surprising, when we have in mind the fact that nuclear engineering originates in the USA. This fact should be considered and given proper importance. There is also the question of a future day which might render the adoption of metric system indispensable? If this question could be answered with certainty, it would be also become clear what should be done. However, if there are indications in such a sense, then there is only one solution: to make the change better sooner than later, because later will mean bigger losses and longer time. Such reasoning is objective and benevolent and it does not result from a nontolerance of the English system nor by a drive to standardize everything.

It is possible, that a less severe but still equally good solution could be found. Should the structure of the English system of measures be made decimal, it would become equivalent to metric. As the length unit, one inch or one foot could be used, or according to Mr. Buchsbaum proposal $\frac{1}{64}$ inch, and all other measures should be decimal fractions and decimal multiples of the chosen unit. The same is valid for weights where the choice could be made between ounce and pound. I presume that passing over to such a decimal system would be easier and that it would involve smaller sacrifice, though the desired goal would be only partly achieved because the units which are used in electricity the world over, namely the ampere, volt, watt, etc. are based on the metric system.

The existence of two different systems of measures is inconvenient for both sides. It is equally inconvenient to use a formula of one system in another as well as to convert drawings from one system into another. It follows: if we accept coexistence of both systems such a compromise is equally hard for all of us, which makes the need for a universal system mutually desirable.

According to the cited article the followers of the metric system have a passion to standardize and to mold everything. To talk about it is out of place if the trend of our time is properly understood. Quick development of techniques in twentieth century requires order and simplifications in the growing variety of its features, as the man of our time is unavoidably confronted with expanding demands, which require greater responsibility and wider knowledge. It should be avoided to complicate for what is possible to find a purposeful and logical simplicity. Human beings differ so widely each from the other that a standardization of customs, habits, even of our way of life is entirely fictitious. There is no place for any fear that through standardization our world may at one day become grey and dull.

COMMENT BY M. ARNOLD BUCHSBAUM

The author appreciates the comments received and the viewpoint expressed. Their tones seem to prove rather than disprove the author's indication of the nature of some advocates of the metric system.

The sinister or foolish imputations read into the author's mind across thousands of miles and many borders has no basis in fact.

The article did not contend that there is anything inferior about the metric system. In fact, it was intended to indicate which features of the metric system could be applied with profit to the English system.

If the question were one of scientific harmony alone, there could be few arguments favoring a permanent retention of more than one system of units.

The universal adoption of any one system, however, reaches far into the political, social, and economic structure of a nation. As an example, is it sensible to change over if 90 per cent of the economy is dependent on and is consistent with the existing system of units, while 10 per cent, let us say the export trade, clashes? It would certainly be far more sensible and economically justifiable to spend a little extra effort in converting the 10 per cent to the needs of the other system, rather than changing the 90 per cent.

Despite great implications of the immediate urgency of the problem of the duality of units, we have existed with it for many years. I suspect it will continue to be with us many more years. The reason for its continued existence will lie in its practical and not scientific aspects. The engineer's job is definitely intertwined with an appreciation of economic needs and he cannot forsake this for the niceties of scientific advantages.

The fact that some esoteric industries such as atomic energy may be on one consistent system of units (although there is doubt on its universal application) only may prove an exception. Our economy depends primarily on the "bread and butter" industries of which shipbuilding is certainly a part. The atomic energy field is but a small and experimental part of the total industrial output, however well publicized it may be.

If we realize how far reaching the proposed changes would affect our daily lives—the weighing scales at homes and in the stores, the automobile speedometers, the carpenters' rule, the quart bottles and gallon jugs, we may with perfect justice ask—is it necessary to change, is it urgent to change? Do we benefit or lose if we change?

BOOK REVIEWS AND NOTICES

MARINE SALVAGE OPERATIONS
by Edward M. Brady
Published in 1960 by Cornell Maritime Press
Cambridge, Massachusetts
256 pages of text and illustrations Price $8.50

Reviewed by
W. L. MARSHALL, Commander, USN
Head, Damage Control, Ship Salvage and Personnel Protection Branch
Bureau of Ships

This is the first handbook or ready reference that has appeared in the American Press on marine salvage. It lists and describes equipment and techniques and the inherent problems which accompany the conduct of salvage operations. It is definitely not written for light reading, but rather as a guide for ship salvage men, divers and seagoing officers and men who need a quick and accurate reference.

The author received his basic salvage training while in the Navy at the U.S. Naval School, Salvage, Bayonne, New Jersey. Those salvage men and divers who are graduates of this school will feel a certain nostalgia with this book since a good deal of the information and some of the illustrations stem from lectures and classroom work of that school. Mr. Brady has done an excellent job of organizing this information and supplementing it with additional data from other sources. The result is a well organized reference text for the working salvage man.

The author's expressed purpose throughout "Marine Salvage Operations" is to point out that the single most important element in all ship salvage work is "Man." No two salvage cases are ever alike even though the same ship might be involved. For this reason, it is essential that the salvage man be well grounded in all the basic principles of this subject and know how to apply them. The best of salvage equipment is of little value unless properly handled and effectively used. Imagination and a cool head are just as essential since the successful salvor must be able to visualize how the selected combination of techniques in a given case will lead to success and this is often necessary under pressure not only from the elements, but also from worried and excited owner's representatives and ships' officers. In this book no attempt has been made to discuss preservation of materials recovered from the sea. The author feels this is a separate subject. In general this is true, but in some cases the initial acts of preservation must be accomplished before the salvage has been completed. These, often hurried and rough, but vital, preservation techniques should have been included in the text in my opinion.

"Marine Salvage Operations" is divided into six main chapters which cover—Types of Ship Salvage—Practical Diving—Naval Architecture—Equipment and Structures Used in Salvage—Salvage Practice—Miscellaneous Salvage Operations, Techniques and Hazards. Three types of ship salvage are defined—Strandings, Sinkings and Rescue Towing. In my opinion the subject of Strandings should be subdivided into Strandings on an open exposed sea

coast where a wreck is exposed to the wind and sea, and Strandings that occur in harbors and protected waterways. It takes a far higher degree of knowlege and skill to refloat a stranded ship on the open sea coast than in protected waters where the effects of the elements are effectively curtailed. The above differentiation is normally made in the U.S. Navy. The Navy also recognizes one additional category of ship salvage, namely, Harbor Clearance. This is the clearing of ships and other wreckage from a badly damaged harbor and would normally occur only in wartime or as a result of a major catastrophe. This type of salvage is actually a multiple type of the Sinking category in this book with the added problems of badly damaged shore facilities and unexploded ordnance and mines. At the end of this chapter, the author states that a vessel should not be sunk below about 150 feet to be considered for salvage. This is too deep except in the case of submarines or vessels that can be raised with pontoons. Normally a surface ship sunk below 50 feet or 60 feet requires extensive shoring of bulkheads and decks. This is costly and time consuming, both increasing very rapidly with depth because of the limitations imposed on the divers as to working time and decompression. Consequently, 50 feet to 60 feet is considered to be the maximum economical salvage depth in most cases. In the chapter on Naval Architecture, Mr. Brady has done an excellent job of providing just sufficient theory to provide the reader with the basic tools he needs. Care has been taken to stress the ship construction and rigging details and the mechanical skills so vital to success in this field. The chapter on Practical Diving gives a good, quick review of the three main types of diving and a comparison of the relative merits of one versus another in salvage work. In the chapter on Salvage Practice, I believe the author should have stressed the difficulties of using compressed air in salvage work even more than he did. These criticisms are minor except in the case of the depth of water at which salvage is practical.

This book fills a need that has been felt for a number of years. It should be in every salvage man's library and available for any other seaman or diver who has a need to delve into the ship salvage business.

"INCOMPRESSIBLE AERODYNAMICS"

Edited by Bryan Thwaites
Published in 1960 by
The Oxford University Press Amen House London E.C.4, Eng.
636 pages of text and illustrations

Reviewed by
J. F. Hillman, Bureau of Ships, Navy Department

This imposing volume, the first of a series of Fluid Motion Memoirs sponsored by the Aeronautical Research Council of Great Britain, contains the contribution of some sixteen collaborators. As the title suggests, the subject matter is oriented principally towards the problems of flight of aircraft; the elimination of compressibility effects in this work, however, brings most of the discussion within the purview of the hydrodynamicist.

The organization of this volume is excellent, proceeding from the more basic material towards more complex and sophisticated topics. There is a refreshing combination of theory and selected experimental data together with some fine illustrations. This combination serves to join two approaches to this subject, the analytical and the empirical, in a manner that will be useful and meaningful to many of us. The sheer mass of data presented, however, will make this volume rather unwieldy as a classroom text.

In this era of ever-increasing velocities, the naval engineer finds himself more and more frequently extending the borders of his watery domain to include topics not previously considered pertinent. To support these forays it becomes increasingly necessary to refer to works in the aerodynamic field. This portion of the memoirs, for which much credit is due Mr. Thwaites, should provide a great deal of this support.

POLARIS

The Concept and Creation of a New and Mighty Weapon

By JAMES BAAR and WILLIAM E. HOWARD

245 Pages $4.50

Published by

Harcourt, Brace & Co.

750 Third Avenue, New York 17, N. Y.

Reviewed by J. E. Hamilton

As an individual, not as an officer of ASNE

The authors of POLARIS are, respectively, Associate Editor for Military Affairs and Managing Editor of *Missiles and Rockets*. Each has a near lifetime background of reporting and editing. They demonstrate, in POLARIS, ability to tell a story clearly, convincingly, and with interest sustaining vigor.

POLARIS is a story of an idea which took 18 years to be translated into hardware; of the men who pushed the idea and possibly of greater importance, of those whose action or inaction kept the program from getting underway or slowed it down later.

It was in 1942 that German scientists fired the first rocket from a submerged submarine. Hitler's bureaucracy killed the concept at that point. In 1945 the idea was reborn in the Navy's Bureau of Ordnance. Hitler was gone but he was not needed. It was ten years later in December 1955 before Rear Admiral (Red) William F. Raborn, Jr., U. S. Navy opened his new Special Projects office with the mission of putting a missile to sea in a submarine in ten years.

In 200 pages the struggle between dogged determination with confidence and imagination against bureaucracy and other evils is described in an interesting and striking fashion. The first operational missile went to sea in a submarine *in less than five years* and not in ten as originally expected. An unparalleled achievement of leadership which gained the loyal cooperation of thousands in industry and the support of a big majority in Congress but with few exceptions had to fight against an attitude of "you've got to show me" in the Department of Defense. Raborn's organization did show them. In October 1960 the *George Washington* and the *Patrick Henry* were proved to be operational. The greatest deterrent to an all-out thermonuclear holocaust was in being.

A peculiarity of this book is that very few things which are said in it did not impress this reader as being something that he had heard or read at the time. The authors have done a remarkable job in bringing all of these events, these facts, into line and relationship so that the entire story appears as a continuum.

The book makes no attempt to present a picture of a one man show. The one man, Admiral Raborn was there but he had the continual support from the top of the Chief of Naval Operations, Admiral Arleigh Burke, and others in the Navy, of many in Congress and the support from below of his entire staff and of thousands of industrial concerns, scientists, management experts and others. The book leaves the impression that the entire job in the Navy Department was done by the Special Projects office. It seems probable that the regular naval organization particularly in the Bureaus of Ships and Ordnance must have made a sizable contribution and the authors might well have added a few pages to clarify this.

One can hardly read this book without conviction that the United States can accomplish anything technological. Given the right leadership the assets of the country are the equal of any and better than most. Furthermore, the right combination is not deterred by difficulties and no opposition is strong enough to stop it, only to hamper, and delay and to make the job harder.

The book presents something of the development of the management tools which contributed to the successful outcome of the POLARIS program. It can be expected that more will be heard of PERT as it is developed by use of electronic processing equipment to digest information received by rapid communications and to turn out condensed facts for consideration by top management in making decisions.

This book deserves wide reading.

BOOKS RECEIVED

"Using Centrifugal Pumps" by E. Allen, published by Oxford University Press, 417 Fifth Avenue, New York 16, New York. 246 pages, $4.80.

"The Mobile Manual for Radio Amateurs," published by The American Radio Relay League, West Hartford, Connecticut. 282 pages, $2.50.

"The A.R.R.L. Antenna Book," published by The American Radio Relay League, West Hartford, Connecticut, 320 pages, $2.00.

"Engineering Mathematics" by J. Blakey and M. Hutton, published by Philosophical Library, Inc., 15 East 40th Street, New York 16, New York. 603 pages, $10.00.

"Transformers and Generators for Power Systems" by R. Langlois-Berthelot, published by Philosophical Library, Inc., 15 East 40th Street, New York 16, New York. 541 pages, $12.00.

"Transactions of the Institution of Naval Architects," Volume 101, 1959, edited by Captain A. D. Duckworth, R.N., published and sold by the Institution of Naval Architects, 10, Upper Belgrave Street, London, S.W.1. 448 pages.

CAPT HENRY C. DINGER

Captain Henry S. Dinger, U.S.N., at the time that he was Director of the Engineering Experiment Station.

On 15 October 1960 in New York City, Henry C. Dinger died at the age of 84. This closed the career of one of the Navy's true pioneers in engineering and shifted the honor of being the oldest surviving past Secretary-Treasurer of the American Society of Naval Engineers to another.

Captain Dinger retired from active duty in the Navy in 1930 after serving for 32 years from his graduation from the Naval Academy with the class of 1898. At the academy he had been an engineering cadet but, because the Engineer Corps had been abolished he graduated as an unrestricted line officer. The class of '98 graduated early, on 2 April to permit its assignment for war duty. Dinger was first assigned to USS *Columbia*; then to USS *Celtic* to participate in the Puerto Rican Campaign and to various ships in the Far East to take part in the Philippine Insurrection and the Boxer Rebellion.

His shore duty was all identified with engineering. When he first reported to the Bureau of Steam Engineering in 1903 he joined the American Society of Naval Engineers. During later tours in the Bureau he served as Secretary-Treasurer of the Society in 1909, 1910 and 1914. In 1909 he made the arrangements for the first banquet which the Society held in Washington.

The following acts and achievements earn him the title of Pioneer Naval Engineer:

In 1903-04 he assisted in writing the report of the Fuel Oil Test Board. This report officially started the general shift from coal to oil as the Navy's fuel;

In 1904 he made recommendations which led to the assignment of the first officer Assistant Chief of Bureau and the First Chief Draftsman in the Bureau;

In 1908 he published a handbook for the Care and Operation of Naval Machinery;

During the same year he supervised the tests of the first U. S. Mechanical Atomization fuel oil burner;

In 1909 he drew up a scheme for special training of young line officers for engineering duty which led to some improvements in the Navy Post Graduate School;

In 1910-11 he commanded USS *Drayton* one of the first group of oil-burning destroyers; and

In the *Drayton* tested the first Sperry Gyro Compass;

In 1912 the USS *Utah* won the Engineering trophy while he was Chief Engineer;

In 1913-16 he prepared the first draft of the General Specifications for Machinery in the Navy;

In 1915 he drafted legislation which was enacted in 1916 and created the officer designated for Engineering Duty Only in the line of the Navy;

He was in the first group to be designated EDO in 1916

In 1916-17 he commanded USS *Maumee*, the first diesel driven naval surface ship and there conducted the first oiling at sea.

Following World War I for his services in which he was awarded the Navy Cross, he served successively as Inspector of Machinery at the Fore River Shipbuilding Plant at Quincy, Mass. 1918-1920; Engineering Superintendent of the Philadelphia Navy Yard 1920-1924; Inspector of Naval Material New York 1924-1926; and Officer in Charge, Engineering Experiment Station 1926-1930. While in the last position he served as chairman of the A.S.M.E. Committee on Diesel Fuel Oil Specifications, developed the Work Factor method for purchase of lubricating oil, packing, etc., and conducted basic research on fatigue and corrosion fatigue of metals.

Captain Dinger retired from active duty in May 1930 and established his home in Philadelphia, later moving to New York City where he was residing at the time of his death. He was a director of the Union Paving Co., of Philadelphia and a Consulting Engineer.

During his retirement, Captain Dinger maintained his interest in the Society and frequently commented on something which appeared in the JOURNAL. His interesting and informative letters were printed in the issues for May 1952, August 1956, November 1956 and November 1959. In 1958 he attended the Society's banquet in Washington but thereafter his health prevented his joining us.

Captain Dinger is survived by a son, Frank; a daughter Sister Maura, O.S.B.; a brother Julius; and six grandchildren. Interment was in Arlington National Cemetary on Wednesday, 19 October 1960.

Facilities for storing, handling, processing and packaging of the low and high level radioactive waste products from the nearly completed nuclear ship *Savannah* will be provided by a special barge built by the Todd Shipyards Corporation yard at Houston, Texas.

The barge, named *Atomic Servant*, was launched on June 8, and has a length of 129 ft., a breadth of 36 ft. and a depth of 14 ft. Structurally the barge is longitudinally framed and has been classed and inspected by the American Bureau of Shipping and the United States Coast Guard for short coastwise service. The hull is subdivided by two longitudinal and eight transverse watertight bulkheads and a double bottom to give two compartment subdivision protection. Above the inner bottom level are the waste processing compartment, laboratory and fuel pit area. These are designated contaminated spaces. The store rooms, cement area, maintenance, workshop, machinery space and switchboard station are regarded as non-contaminated areas.

Within the large deckhouse on the main deck are the decontamination and workshop areas, personnel de-contamination room, changing area and laundry. Non-contaminated spaces on the main deck include the first-aid room, issue room, locker area and toilets. An operations center is located on top of the deckhouse and alongside is a small pantry and a fan room.

Isolation of the decontamination spaces is maintained by a ventilation system arranged so that the air-flow is always from a non-contaminated area to a contaminated area and is then discharged through a system of filters up an exhaust pipe. This air-discharge is continuously monitored for radioactivity.

For the handling of certain heavy components and general service a diesel-engined revolving marine crane is provided with a capacity of 10 short tons at 35 ft. radius and using a 50 ft. boom.

—SHIPBUILDING AND SHIPPING RECORD
July 21, 1960

Non-propelled barge *Atomic Servant* designed to serve the nuclear ship *Savannah*.

CHANGES IN MEMBERSHIP

ADDITIONS TO MEMBERSHIP

The Society announces with pleasure that the following have joined its ranks since the publication of the August 1960 issue of the JOURNAL.

NAVAL

Andrews, B. H., CAPT., USN
Mail: USN Underwater Sound Laboratory, New London, Conn.

Ballantine, James Clement, Jr., LTJG., USN
Mail: USS *Pickerel* (SS524), c/o FPO, San Francisco, Calif.

Bresler, Harvey, LCDR, USNR
Federal Aviation Agency
Mail: 3141 Quesada St., N.W., Washington 15, D.C.

Cadwell, George Mason, Jr., ENS., USN
Mail: USS *Capricornus* (AKA-57), c/o FPO, New York, N. Y.

Filkins, William C., LT., USN
Mail: 2259 Bellfield Ave., Cleveland Heights 6, Ohio

Gilfeather, Frank George, Jr., LTJG, USNR
Mechanical Engineer, Raytheon Mfg. Co.,
Box 160, Wayland Lab., Wayland, Mass.

Hamwey, Robert Michael, LTJG, USNR
Methods Programmer, I.B.M.
Mail: 8504 - 16th Street, Apt. 304, Silver Spring, Md.

Lehman, Benjamin J., CDR, USNR
Supervisory Engineer, Lockheed Aircraft Co.,
Missiles and Space Div., Van Nuys, Calif.
Mail: 201 Creekside Drive, Palo Alto, Calif.

Nelles, Merice Tilman, LT., USN
Mail: Naval Ordnance Facility, Navy #3923,
Box 6, c/o FPO, San Francisco, Calif.

Peebles, Edward Metcalfe, LT., USN
Mail: 165 Foster Street, Brighton 35, Mass.

Phin, Sydney Neill, ENS., USN
Mail: 64 Ridge Road, New City, N. Y.

Porter, George W., Jr., LT., USN
Asst. Professor, Naval Science, University of Texas
Mail: c/o NROTC Unit,
The University of Texas, Austin, Texas

Salmon, Ronald Dean, Brigadier General, USMC (Ret)
Mail: 640 Oakland Terrace, Alexandria, Va.

Swanson, Harlan David, LT., USN
Mail: 55 West Cedar Street, Boston 14, Mass.

Turner, Clifford O., Jr., LTJG, USNR-R
Mail: 315 South Pickens Street, Columbia, S. C.

Veasey, Alexander Craig, CAPT., USN
Mail: Chief, Navy Section, MAAG, Japan,
APO 900, San Francisco, Calif.

CIVIL

Atkin, Kenneth Clair
Senior Design Engineer, Convair,
Division of General Dynamics
Mail: 5051 Mt. Harris Drive, San Diego 17, Calif.

Crouch, Robert B.
Scientific Advisor, Corporate Development Planning,
Lockheed Aircraft, Burbank, Calif.

Hobbs, Robert William
Naval Architect and Engineer
Mail: 7275 S.W. 104th Street, Kendall,
Miami 56, Fla.

Schulz, Fred R.
Manager, L. J. Wing Mfg. Co.,
2300 N. Stiles Street, Linden, N. J.

Shenk, Robert H.
Vice President, Technical Director, Zurn Industries
Mail: 3416 Colonial Avenue, Erie, Penna.

Ward, Lawrence Waterman
Professor of Engineering, Webb Institute of Naval Architecture, Crescent Beach Road, Glen Cove, Long Island, N. Y.

ASSOCIATE

Cravens, William Murphy, III
Manager, Navy Sales, General Electric Co.
Mail: 10423 Montrose Avenue, Apt. 101, Bethesda 14, Md.

Thane, Aung, Commander (E), Burma Navy
Chief Engineer, Burma Navy,
c/o US Naval Attache, Rangoon, Box "R",
APO 146, San Francisco, Calif.

JUNIOR

Smith, Walter Alexander
Class of 1961, New York State Maritime College
Mail: Aeroflex Corp., Aeroflex Andover Field, Box 193, R.D. 1, Newton, N. J.

TRANSFERS

Hume, George ..... *Associate to Civil*
McCord, Harlow C. ..... *Associate to Civil*
Weber, C. Swan ..... *Naval to Civil*

DEATHS

Brace, Norman G. ..... *Civil*
Curran, Paul M., CAPT., USN (Ret) ..... *Naval*
Dinger, H. C., CAPT., USN (Ret) ..... *Life*
Higgins, Harry A., LT., USNR ..... *Naval*
Klinedinst, Milford S. ..... *Civil*
Parker, Herbert C. ..... *Naval*

ASSOCIATION NOTES

ORIGINAL ARTICLES

The editor of the JOURNAL is most anxious to obtain manuscripts of original articles on subjects of interest to naval engineers. Any manuscript accepted for publication becomes the property of the Society which copyrights it upon publication. Authors are paid from $50.00 to $250.00 depending upon length, interest and professional value. Payment is made at time of acceptance.

The rules for manuscripts are as simple as we can make them.

1. They must be legible (typewritten, double-spaced preferred) since no proof is submitted to authors for correction prior to printing.

2. Single copy only is required.

3. Mathematical formulae used must be set up, preferably by hand printing, so that there can be no question as to symbols, subscripts and exponents.

4. Any drawing submitted must be black on white. A cloth or paper tracing is acceptable but not required.

5. Photographs may be negatives, but glossy prints are acceptable.

6. *Include on a separate page a short biographical sketch(es) of the author(s).* 50 to 100 words for each author is desired.

Manuscripts should be addressed to:

Secretary-Treasurer
American Society of Naval Engineers, Inc.
1012 14th St., N.W.
Washington 5, D.C.

Each author who is subject to the Security Regulations of the Department of Defense, is personally responsible for the clearance of an original article before submitting it to the Society for consideration. In forwarding manuscripts, a statement in this regard should be included.

Manuscripts accepted will not be returned unless specifically requested by the author. If returned, they will be in the condition which has resulted from the work of the printer and the engraver. Immediately following publication, the author is furnished 20 reprint copies of his article free of charge. Additional copies may be purchased from the Society *if the request is received 30 days prior to the publication date which is the 25th of the issue month.* Estimate of cost of additional reprints, which will vary with the nature of the article and the number of copies ordered, will be furnished on request as soon as possible after the article is set up.

Manuscripts not accepted will be returned, postpaid, by the Society.

Manuscripts which are accepted will be published in the earliest JOURNAL which has not yet been closed (60 days before publication) and for which sufficient material is not already on hand.

ASSOCIATION NOTES

PHOTOGRAPHS

Photographs of current or historical interest to readers of the JOURNAL are desired. Any which are accepted by the Society will be purchased by the Society at a standard price of $5.00 each. Such purchase *will not* include any copyright by the Society, but the contributor must hold the Society free from any charge of violation of any previous copyright.

NOTICE OF DEATHS

The Society has no satisfactory machinery for obtaining notice of deaths of members. It is particularly desired that we receive such notice upon the death of any past officer, past member of the Council or member of more than twenty years' standing with photographs and short obituaries. It will be appreciated greatly if any member who learns of the death of a member will advise the Secretary-Treasurer.

COPIES OF JOURNALS

The Society has made arrangements with the Johnson Reprint Corp. to be our sole representative for the sale of copies or reproductions of any Journals or parts of Journals which were printed prior to 1951. Any requests or inquiries which are received by the Society for these will be forwarded without any action by us.

When making inquiries as to the procurement of or orders for copies or portions of any Journal from Volume 1 (1889) through Volume 62 (1950) please address

Johnson Reprint Corp.
111 5th Avenue, New York, N.Y.

For Volume 63 (1951) and later address the Society.

PERMISSION TO REPRINT

All material published in the JOURNAL, except the articles which are prefaced with an "Acknowledgement," are copyrighted by the American Society of Naval Engineers.

Permission is granted to reprint any copyrighted material contained herein if the following conditions are met:

a) The article is reprinted in full. Extracts or summaries or condensations may be printed with the consent of the author.

b) Credit is given to the JOURNAL with reference to the issue.

c) Credit is given to the author.

d) If the author is a military officer or a civilian employee of the Department of Defense, the following note shall be carried:

"The views expressed herein are the personal opinions of the author and are not necessarily the official views of the Department of Defense or of a Military Department."

APPLICATION FOR MEMBERSHIP

IN THE AMERICAN SOCIETY OF NAVAL ENGINEERS, INC.

(See reverse side for required qualifications for various classes of membership)

Date _____

I, _____ hereby apply for membership in the American Society of Naval Engineers, Inc., and enclose $10.00 as my annual membership dues for the year _____ $8.00 of which is for a subscription to the JOURNAL OF THE AMERICAN SOCIETY OF NAVAL ENGINEERS, INC., for one year. I submit the following information:

For Naval Membership

Name _____
(First) (Middle) (Last)

Rank _____ File No. _____

Business connection and position, if any _____

For Civil Membership

Name _____
(First) (Middle) (Last)

Years in engineering work _____

Years in responsible charge of important work _____

Present business connection and position _____

Recommended by (two members) _____

_____

For Associate Membership

Name _____
(First) (Middle) (Last)

Rank, if Commissioned Officer of U.S. Army or of foreign military or Naval service _____

Business connection and position _____

Recommended by (one member) _____

_____

Signature of Applicant

Address for JOURNAL and Mail

_____

_____

MAIL TO SECRETARY-TREASURER

THE AMERICAN SOCIETY OF NAVAL ENGINEERS, INC.

Suite 403, Continental Building

1012 14th St., N.W. Washington 5, D.C.

Company Memberships Not Available

QUALIFICATION FOR MEMBERSHIP

Commissioned and ex-commissioned officers, warrant and ex-warrant officers, and reserve (commissioned and warrant) officers of the Navy, Coast Guard and Marine Corps, of the United States, active or retired, shall be eligible as Naval Members. Persons eligible as Naval Members shall be admitted upon application and payment of annual dues.

Persons in civil life whose knowledge of engineering is such that they can cooperate with Naval engineers in the promotion of professional knowledge may be eligible as Civil Members. They shall have been in the active practice of an engineering profession for at least eight years and in responsible charge of important work for five years, and shall be qualified to design as well as to direct engineering work. Fulfilling the duties of a professor of engineering who is in charge of a department in a college or school of accepted standing shall be taken as an equivalent to an equal number of years of active practice. Graduation from a school of engineering of recognized standing shall be considered as equivalent to two years of active practice. Persons eligible as Civil Members may be admitted upon application and payment of annual dues, provided that the application is accompanied by the recommendation of two members and provided that the application shall receive the approval of a majority of the Council.

Persons in civil life who are not eligible for civil membership, but who are especially interested in naval matters or the merchant marine may be eligible as Associate Members. Commissioned officers of the United States Army, United States Air Force and of foreign military and naval services may be eligible as associate members. Persons eligible to associate membership may be admitted upon application and payment of annual dues, provided the application has the recommendation of a member and provided the application shall receive the approval of a majority of the Council, except that in the case of commissioned officers of the United States Army, of the United States Air Force, and of foreign naval and military services, the recommendation of a member will not be required.

Undergraduates at schools to be named by and under regulations to be issued by the Council shall be admitted as Junior Members at one-half the dues of regular members during their course and for one year following graduation, after which time junior membership will be terminated, the member to have the privilege of transferring to regular membership in the appropriate category.

Associate and Junior Members shall be entitled to all the privileges of other members except voting and holding office.

The annual dues shall be $10.00, payable on 1 January in advance, of which $8.00 shall be for subscription to the JOURNAL of the American Society of Naval Engineers, Inc., for one year.

COMPANY MEMBERSHIPS NOT AVAILABLE

INDEX TO ADVERTISERS

For discussion in regard to the change in positioning of advertisements, please turn to and read page 603.

Advertisers Name	*Post Office Address*	*Page*
American Brass Co.	Waterbury, Conn.	628
Babcock and Wilcox	Barberton, Ohio	632
Bath Iron Works	Bath, Maine	608
Bethlehem Steel Co., Shipbldg. Div.	25 Broadway, New York, N.Y.	642
Bird-Johnson Co.	21 West Street, New York 2, N.Y.	778
Buffalo Pumps Div., Buffalo Forge Co.	490 Broadway, Buffalo 5, N.Y.	698
Combustion Engineering Co.	200 Madison Ave., New York, N.Y.	690
De Laval Steam Turbine Co.	Nottingham Way, Trenton 2, N.J.	750-51
Gibbs and Cox, Inc.	New York, N.Y.	658
Henry, J. J. Co., Inc.	21 West Street, New York 6, N.Y.	658
International Nickel Co.	Huntington 17, West Virginia	764
Kingsbury Machine Works	Frankford, Philadelphia 24, Pa.	652
Lucian Q. Moffitt, Inc.	Akron, Ohio	639
Newport News Shipbldg. and Drydock Co.	Newport News, Va.	726
Radio Corporation of America	Camden, N. J.	736
Rosenblatt, M. & Son	350 Broadway, New York, N.Y.	658
Solar Aircraft Co.	San Diego 12, Calif.	666
Sperry	Great Neck, N.Y.	758
Terry Steam Turbine Co.	Hartford, Conn.	665
Texaco, Inc.	135 E. 42nd St., N.Y. 17, N.Y.	752
Westinghouse	3 Gateway Center, Pittsburgh 30, Pa.	640-41
Whittelsey, H. Newton	17 Battery Place, N.Y. 4, N.Y.	658
Worthington Corporation	Harrison, N.J.	691-92

THE 1961 ANNUAL BANQUET

of

The American Society Of

Naval Engineers

will be held at

HOTEL STATLER-HILTON

WASHINGTON, D. C.

on

Friday, 28 April 1961

Notices with application forms will be mailed to all members in February 1960

1888
1890
1891
1892
1894
1896
1898
1899
1900
1901
1902
1903
1904
1905
1906
1907-
1908-
1911
1912
1912
1913
1914

1939-
1941-
1945
1945-

*Name

Secretaries of the

AMERICAN SOCIETY OF NAVAL ENGINEERS, INC.

Captain J. E. Hamilton, U. S. Navy Retired, Secretary-Treasurer
Commander Joe W. Thornbury, U.S.N., Assistant Secretary-Treasurer

---

Past Secretaries

1889 *P. A. Engineer R. S. Griffin, U. S. Navy*
1890 *Assistant Engineer W. M. McFarland, U. S. Navy*
1891 *Assistant Engineer Emil Theiss, U. S. Navy*
1892–93 *P. A. Engineer W. M. McFarland, U. S. Navy*
1894–95 *P. A. Engineer R. S. Griffin, U. S. Navy*
1896–97 *P. A. Engineer F. C. Bieg, U. S. Navy*
1898 *P. A. Engineer W. M. McFarland, U. S. Navy*
1899 *Chief Engineer A. B. Willits, U. S. Navy*
1900 *Lt. Comdr. A. B. Willits, U. S. Navy*
1901 *Lieutenant B. C. Bryan, U. S. Navy*
1902 *Lieutenant C. W. Dyson, U. S. Navy*
1903 *Lt. Comdr. John R. Edwards, U. S. Navy*
1904 *Lieutenant M. E. Reed, U. S. Navy*
1905 *Lieutenant W. W. White, U. S. Navy*
1906 *Lieutenant C. K. Mallory, U. S. Navy*
1907–08 *Lt. Comdr. T. C. Fenton, U. S. Navy*
1908–10 *Lieutenant H. C. Dinger, U. S. Navy*
1911 *Commander U. T. Holmes, U. S. Navy*
1912 *Lieutenant John Halligan, U. S. Navy*
1912 *Lt. Comdr. E. L. Bennett, U. S. Navy*
1913 **Lieutenant O. L. Cox, U. S. Navy**
1914 *Lt. Comdr. H. C. Dinger, U. S. Navy*
1915–16 *Lieutenant A. T. Church, U. S. Navy*
1917 **Lt. Comdr. J. O. Richardson, U. S. Navy**
1917–19 *Lt. Comdr. F. W. Sterling, U. S. Navy*
1919–21 **Commander J. S. Evans, U. S. Navy**
1921–23 **Commander S. M. Robinson, U. S. Navy**
1924–25 **Commander Bryson Bruce, U. S. Navy**
1926 **Commander A. M. Charlton, U. S. Navy**
1927–28 **Commander H. B. Hird, U. S. Navy**
1928 **Captain O. L. Cox, U. S. Navy**
1929–30 *Commander H. T. Smith, U. S. Navy*
1931 **Captain O. L. Cox, U. S. Navy**
1932 **Commander H. F. D. Davis, U. S. Navy**
1933–34 **Commander H. B. Hird, U. S. Navy**
1935–36 *Commander C. S. Gillette, U. S. Navy*
1936–38 **Commander Roger W. Paine, U. S. Navy**
1938–40 **Lt. Comdr. Guy Chadwick, U. S. Navy**
1940–44 **Captain J. E. Hamilton, U. S. Navy**
1945 **Commander R. T. Sutherland, Jr., U. S. Navy**
1945–48 **Captain F. W. Walton, U. S. Navy**
1948–51 **Captain J. E. Hamilton, U. S. Navy**

Past Assistant Secretaries

1939–40 **Lieutenant Milo B. Williams (C.C.) U. S. Navy**
1941–44 **Lt. Comdr. Robert T. Sutherland, Jr., U. S. Navy**
1945 **Captain F. W. Walton, U. S. Navy**
1945–47 **Commander Floyd B. Schultz, U. S. Navy**
1947–49 **Commander C. H. Meigs, U. S. Navy**
1949–50 **Commander Frank C. Jones, U. S. Navy**
1951–59 **Captain Robert B. Madden, U. S. Navy**
1959–60 **Commander Charles N. Payne, U. S. Navy**

Clerk and Administrative Assistant

1908–58 **Mr. Arthur G. Fessenden**

1958– **Miss Ruth M. Leonard**

---

*Names in italics deceased

NOVEMBER 1960

TABLE OF CONTENTS

		Page
SECRETARY'S NOTES		601
Plastics	OWEN & ALFERS	609
Theory of Specific Heats	POTTER	623
Magnetohydrodynamics	Reprint	629
Liner Machinery Proposals	Reprint	633
Nuclear Power	Reprint	643
Graphical Checking of Test Data	SCHENCK	653
Forebody Damage	Reprint	659
Gas Turbine Propulsion	Reprint	667
Modern Models	HERR	673
Soviet Engineering Notes	KASSELL	675
Pressurized Water Reactors Control	STIRLING	693
Pump Auxiliaries	Reprint	699
Plasma Pinch Space Engine	GRANET, GUMAN and McILROY	715
Pebble Bed Reactor	BOSNAK	727
Work Measurement	DESEL and CARLOW	737
Gear Lubricants	Reprint	749
New Marine Nuclear Power Plant	GARAY	755
John Sergeant Gas Turbine	Reprint	761
Management Information	BRAGG and HINCKS	773
Liquid Metal Heat Exchangers	SCHUMACHER	779
Two Systems of Measure	GASPAROVIC	783
Departments		785